JOURNAL OF AGRICULTURAL RESEARCH

VOL. XIX WASHINGTON, D. C., SEPTEMBER 1, 1920 NO. 11

GENETICS OF RUST RESISTANCE IN CROSSES OF VARIETIES OF TRITICUM VULGARE WITH VARIETIES OF T. DURUM AND T. DICOCCUM [1]

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INTRODUCTION

The black stemrust (*Puccinia graminis*) of small grains causes enormous losses. Reduction in yield of from 10 to 50 per cent of the wheat crop is common. At irregular intervals the black stemrust of wheat causes almost complete failure, especially in the spring-wheat area of the upper Mississippi Valley. Control of this disease, which develops into such terrific epidemics, is impossible by any method now available to the individual grower. For this reason the development of resistant varieties assumes great importance. While the barberry eradication campaign now being carried on over a wide area will certainly reduce the amount of rust, local outbreaks may perhaps be expected even after barberries have apparently been eradicated. The attempt to develop resistant varieties, therefore, should continue. There is every reason to hope that the stemrust problem can be solved by barberry eradication and the development of resistant wheat varieties.

When the present study was outlined, the evidence seemed to show that parasitic action of the rust was constant. Recent extensive studies (*22*, *23*)[3] have confirmed this view and indicate that the bridging hypothesis (*11*), which was supposed to account for the increase or decrease in

[1] Published with the approval of the Director as Paper 187, Journal Series, Minnesota Agricultural Experiment Station. Cooperative investigation between the Minnesota Agricultural Experiment Station and the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture.

[2] The breeding of spring wheat for rust resistance was begun by Dr. E. M. Freeman and E. C. Johnson in 1908 and has been continued without interruption until the present time. The present cooperative arrangement between the Division of Plant Pathology and Botany and the Section of Plant Breeding, Division of Agronomy and Farm Management, of the University of Minnesota, was made in the spring of 1916. The writers wish to acknowledge the helpful cooperation of Dr. E. M. Freeman and Dr. E. C. Stakman in this investigation.

[3] Reference is made by number (italic) to "Literature cited," pp. 541-542.

virulence of the rust, is probably incorrect. More recent investigations of the wheatrust fungus have shown that there are numerous biologic forms (25) which can be differentiated only by their action on various pure-line wheat varieties. This is a very serious obstacle to the production of rust-resistant varieties by breeding, although the fact that Khapli (C I 4013),[1] an emmer imported from India, is resistant to all biologic forms so far isolated shows that the problem is not entirely hopeless.

Former breeding investigations have determined which varieties of wheat are commonly resistant to stemrust at University Farm, St. Paul, and have also indicated the behavior of rust resistance in crosses. In the light of this information it was decided to make a careful genetic study of one or two crosses, hoping thus to solve the plant-breeding phase of the rust-resistance problem. The second generation of the crosses reported in this paper had already been studied before it was known that there were sometimes numerous biologic forms of the rust in the same locality. It seemed worth while to complete the study of inheritance of rust resistance in these crosses by growing a small F_3 family of each F_2 plant which produced viable seed. All barberry bushes were removed from the immediate vicinity of the rust plot early in the spring of 1918, and the artificially induced epidemic was produced with a known racial strain of the biologic form *Puccinia graminis tritici* Erikss. and Henn. Therefore, the greater part, if not all, of the rust infection present during the season of 1918 was due to this one biologic form. One uredinium found on Kanred (C I 5146), which is known to be resistant to the strain which was used to induce the epidemic, proved to belong to another biologic form.

The present paper is a report of the inheritance of rust resistance in its correlation with botanical and morphological characters of crosses between *Triticum vulgare* with varieties of *T. durum* and *T. dicoccum*.

SOME PREVIOUS CROSSES OF WHEAT SPECIES

Because of the many differential characters and the great economic importance of the crop, wheat has been frequently used in studies of the laws of inheritance. Vilmorin (26, 27) reported quite extensive tests of crosses between *Triticum sativum* L., *T. turgidum*, *T. durum* Desf., *T. polonicum* L., and *T. spelta*. From the Mendelian standpoint the results obtained are interesting. He observed remarkable uniformity in the F_1 generation, wide diversity in the F_2 generation, and states that the predominating force after the F_3 generation is that of heredity, which compels the plants to reproduce their characters in their immediate descendants. Vilmorin placed spelt and common wheats in one group and poulard and durum in another, because he found that either spelt or common crossed with poulard or durum produced all four types in the

[1] Cereal investigations number.

segregating generations. These types were easily fixed after several years of selection. The four types were believed to have a common ancestry and to belong to one botanical species. Unsuccessful attempts were made to cross these species with *T. monococcum* L. This led Vilmorin to conclude that *T. monococcum* belonged to a separate species.

Tschermak (*25*) confirmed Vilmorin's conclusions regarding the production of common, durum, spelt, and poulard forms from crosses when the groups differed in the solid and hollow stem character. He stated that the polonicum type was obtained only when it was used as one of the parents. Relationships were illustrated on a factor hypothesis by assuming (1) that *Triticum polonicum* contained two dominant factors, (2) that common wheat lacked these factors, and (3) that durum contained one of these factors but not the other. Tschermak also thinks that *T. monococcum* is different from other wheat species. He obtained hybrids between *T. monococcum* and *T. vulgare* and one F_2 plant, which soon died.

Blaringhem (*6*), however, succeeded in crossing *Triticum durum* and *T. polonicum* with *T. monococcum*. Sterility was at first of frequent occurrence in these crosses, but in later generations it was much less common.

Explorations by Aaronsohn in 1906 (*1*) confirm the experimental evidence cited above. A wild emmer, *Triticum dicoccum dicoccoides*,[1] found in 1906, is interesting because it tends to confirm the report that such an emmer was collected as early as 1885.

Crosses between Black Winter emmer and Fultzo-Mediterranean (*15*) had strongly keeled glumes with hard, adherent chaff in the F_1 generation. The F_2 plants varied widely in type and exhibited transgressive segregation for some characters. There was considerable sterility in this cross. The hairy chaff and black color of the emmer parent were linked in inheritance.

Freeman (*12*) found evidence of linkage between high ratio of width to thickness of head and hardness of grain in a cross between durum wheat and a variety of bread wheat. The bread wheat parent had a square head with soft, opaque grains, while the durum parent had a much flattened head and produced hard, translucent grains.

In a recent article on heredity of quantitative characters in wheat (*13*) a cross between durum and common wheat is reported. It gave normally vigorous plants in the F_1 generation. In the F_2 generation, however, many seeds failed to germinate; and among those with a normal vegetative development were found plants exhibiting every degree of sterility, from perfectly sterile to fertile plants.

Linkage has been reported by Engledow and Biffen in crosses between Rivet, *Triticum turgidum*, and common Fife wheat. Gray glume color

[1] From a cross between durum and common varieties, Love and Craig have produced a form which closely resembles the wild emmer. LOVE, H. H., and CRAIG, W. T. THE SYNTHETIC PRODUCTION OF WILD WHEAT FORMS. *In* Jour. Hered., v. 10, no. 2, p. 51–64, illus.

(*4*) was always found associated with hairy chaff, and partial linkage (*10*) was found between the factors for black color and the factors for glabrous chaff.

Since sterility has been found by many investigators in wheat crosses and has been confirmed by the results presented in this paper, it seems rather difficult to reach any conclusion regarding linkage, because some combinations may be eliminated.

The inheritance of the principal botanical characters of our cultivated wheats is well known and, therefore, need not be summarized in this paper. The inheritance of beards will be mentioned in connection with our results on sterility. In crosses between the so-called beardless wheats such as Marquis and Bluestem and a bearded variety, the F_1 generation has intermediate awns and in the F_2 generation a 1 to 2 to 1 ratio is obtained. Fully bearded plants breed true in the F_3 generation. Howard and Howard (*14*) found that there are two classes of wheats with short awns which, when crossed, give fully bearded plants in the F_2 generation and breed true in the F_3 generation. Likewise, crosses between bearded and true beardless forms gave 1 fully bearded plant in the F_2 generation out of 16 plants. The fact of interest for our studies is that fully bearded plants breed true for this character.

PREVIOUS STUDIES ON INHERITANCE OF RUST RESISTANCE

The most successful attempt to breed rust-resistant wheats was made by Biffen (*2, 3, 5*), who found that resistance to striperust (*Puccinia glumarum* Erikss. and Henn.) was a recessive character. Definite segregation occurred in the F_2 generation, and forms bred true in the F_3 generation, the ratio of resistant to susceptible in the segregating families being 1 to 3. From the practical standpoint these experiments have been very valuable. A new variety, Little Joss, was produced, which, because of its rust resistance, yields more on the average than susceptible sorts and has desirable milling characters.

Nilsson-Ehle (*20*) has likewise made studies of the inheritance of resistance to striperust. Distinct dominance of susceptibility was seldom found. Ordinarily the F_1 generation was intermediate, and in other cases resemblance to one or the other parent was observed. Segregation was obtained in the F_2 generation, but without definite ratios. Transgressive segregation occurred, forms being obtained which were more susceptible than the susceptible parent and others which were more resistant than the resistant parent. The results were explained on the basis of multiple factors.

While many observations have been made on resistance of wheat varieties, the two experiments cited above are the only carefully controlled studies so far reported which show the mode of inheritance.

METHODS OF STUDYING INHERITANCE OF RUST RESISTANCE

In the studies here recorded crosses were made between Marquis and resistant durum and emmer wheats. Precautions were taken to protect the emasculated heads from foreign pollen. The F_1 plants were grown in individually spaced plots, and seed from each F_1 plant was grown separately. The F_2 families of crosses between the same parent varieties gave similar results and were considered as a single cross. No effort was made with either the F_1 or F_2 plants to protect them from natural crossing, and an error was thus introduced which will be discussed later.

The correlation between resistance in the F_1 and the F_2 generations gave unusual results which indicated that some uncontrolled factor was causing complications. For example, the F_1 cross between emmer and Marquis which was grown in 1916 appeared resistant, while in the F_2 generation which was grown in 1917 the number of resistant plants was much smaller than would be expected if resistance were a dominant character. This led to the belief that very likely more than one biologic form of stemrust was present in 1917.

Each F_2 plant which produced viable seed was tested in 1918. As previously mentioned, the barberry bushes were removed from the immediate vicinity of the rust plot early in the spring of 1918. An epidemic was obtained with a known strain of *Puccinia graminis tritici* which had been cultured in the greenhouse by the Section of Plant Pathology for several generations. This strain had been tested repeatedly on varieties of wheat and proved to be constant.

The 1918 results have been used to determine the resistance or susceptibility of F_2 plants which have been grown the previous season. The F_3 as well as the F_2 data have been used as a basis for placing the F_2 plants in certain botanical groups, for the problem was chiefly to determine the mode of inheritance and correlation of resistance or susceptibility with those botanical characters which are commonly used in differentiating wheat species, some of which are also of economic importance.

STERILITY IN THE CROSSES OF MARQUIS WITH DURUM AND EMMER VARIETIES

In order to determine whether there is any interrelation between botanical characters and rust resistance, the data for each F_2 plant were taken in a correlated manner. The practical significance is obvious. For example, if durum head and seed characters were rather closely linked with rust resistance in inheritance, it would be necessary to grow a larger F_2 population to obtain the desired form than if each character were inherited independently. In deciding regarding possible linkage it is important to know whether sterility is involved in the crosses.

Sterility might cause the elimination of certain gametic or zygotic combinations, thus actually eliminating the sort desired. Zygotic combinations are sometimes eliminated as is the case with the homozygous yellow mouse combination (*7, 17*) and with lethal factors in Drosophila (*19*). In some cases gametic combinations are eliminated. Such eliminations occur as a result of pollen or ovule abortion.

POLLEN ABORTION

The presence of shriveled or abortive pollen grains is one means of recognizing sterility. The method here used was to shake out pollen from the heads upon a clean glass slide and then place a minute drop of fuchsin on the pollen, then a drop of lactic acid, and a cover glass.[1] By this method pollen was preserved for several weeks and could be studied when it was convenient.

The parent plants and F_1 crosses were grown in 6-inch pots in the greenhouse. A small percentage of small, globular, clear pollen grains were observed. These, together with the occasional shriveled grains, were counted as sterile. The results of these counts are given in Table I.

TABLE I.—*Counts of sterile pollen grains in wheat species and F_1 crosses between them*

	Variety.	Good pollen.	Poor pollen.
Parental species:			
Triticum vulgare	Marquis	513	4
Triticum durum	Mindum	135	2
Triticum durum	Kubanka (C I 2094)	122	3
Triticum dicoccum	Emmer (Minn. 1165)	169	0
F_1 crosses:			
Marquis × emmer (Minn. 1165)		475	19
Emmer (Minn. 1165) × Marquis		340	37
Kubanka (C I 2094) × Marquis		113	9
Marquis × Kubanka (C I 2094)		151	20
Marquis × Mindum		101	12

These results show that there is a larger percentage of shriveled and abortive grains in the crosses than in the parental varieties. There is also an indication of more pollen abortion in the durum-Marquis crosses than in the cross between emmer and Marquis.

COMPARISON OF NUMBER OF SEEDS SET IN F_1 GENERATION AND PARENTS

As a further test of sterility, counts were made of the number of barren florets in several F_1 crosses and their parents.

There are two or more flowers in each wheat spikelet, and usually two or three kernels mature. The outer florets of each spikelet are usually most vigorous, and when only two florets per spikelet produce kernels these are usually the outside ones. Therefore, the two outer florets of

[1] Outlined to the writers by Dr. C. O. Rosendahl, Professor of Botany, University of Minnesota.

each spikelet were examined. The result of this examination, together with the percentage of barren florets, is summarized in Table II.

TABLE II.—*Number of florets not setting seed in Triticum vulgare, T. durum, T. dicoccum, and F_1 crosses of T. vulgare with T. durum and T. dicoccum*

Variety or cross.	Classification.	Number of heads.	Number of florets examined.	Number of good seed.	Number of very badly shriveled seed.	Percentage of barren florets.
Marquis	*Vulgare*	15	369	341	14	3.8
Preston (Minn. 188)	do	17	528	500	1	5.1
Pioneer	do	26	804	761	1	5.2
Average						4.7
D-4	*Durum*	16	538	499	13	4.8
Iumillo (C I 1736)	do	16	494	464	1	5.9
Kubanka (C I 2094)	do	25	898	864	2	3.6
Acme	do	18	622	604	0	2.9
Average						4.3
Emmer (Minn. 1165)	*Dicoccum*	22	630	611	6	2.1
Kubanka (C I 2094) × Marquis.	*Durum* × *vulgare*	12	426	206	9	49.5
Acme × Preston	do	3	104	62	5	35.6
D-4 × Pioneer	do	9	262	97	17	56.5
Average						47.2
Marquis × Kubanka (C I 2094).	*Vulgare* × *durum*	49	1,692	704	97	52.7
Marquis × Iumillo (C I 1736).	do	4	135	84	9	31.1
Pioneer × D-4	do	9	296	128	11	53.0
Preston × Acme	do	10	348	167	10	49.1
Average						46.5
Emmer × Marquis	*Dicoccum* × *vulgare*	14	410	299	17	22.9
Emmer × Preston	do	13	446	293	25	28.7
Average						25.8
Marquis × emmer	*Vulgare* × *dicoccum*	9	270	184	10	28.2
Preston × emmer	do	3	94	62	4	29.8
Average						29.0

The main spike of individual plants of the parent and crosses was used for this study. There was an average of 4.7 per cent of barren florets in three varieties of *Triticum vulgare*. In four varieties of *T. durum* there was an average of 4.3 per cent, while emmer (Minnesota 1165) produced only 2.1 per cent of florets which formed no kernels. Since these are presumably homozygous, it seems fair to conclude that the percentages given show the average number of florets which did not set seed on account of causes other than sterility.

Three F_1 crosses were studied in which a durum sort was the female parent and four in which durum was the male parent. The average

percentages of barren florets were 47.2 and 46.5, respectively. There was about the same percentage of barrenness in emmer × Marquis, emmer × Preston, and reciprocals—namely, 25.8 when emmer was the female parent and 29 when emmer was the male parent. Thus, there is apparently more sterility in the durum-Marquis cross than in the cross between emmer and Marquis.

Although no cytological examination was made to determine the time of degeneration, it seems very likely that there is ovule as well as pollen abortion. Barren florets, however, might be due to incompatibility of certain genetic combinations or to slow growth of the pollen tube which has been shown to occur in some species crosses (*8*, *9*).

NATURAL CROSSES AS A POSSIBLE INDICATION OF STERILITY

In 1917 the F_2 generation of durum × Marquis and durum × Haynes Bluestem, as well as the parent sorts, were grown together. Marquis is an awnless, glabrous chaffed wheat, Bluestem is an awnless wheat and has pubescent chaff, while the durum varieties used have glabrous chaff and are bearded. In the F_2 generation of the durum-Marquis cross there were a few individual plants with hairy chaff. Since these may have been the result of natural hybridization, these plants were eliminated from further consideration.

In the F_3 families of the durum-Marquis cross, each of which came from an individual F_2 plant, there were some hairy-chaffed plants. In some families the number of plants with hairy chaff was rather large, and counts were made to determine the frequency of their occurrence. Fully bearded plants have always been found to breed true for this character (*14*). This fact supports the view that natural crossing may be the cause of the hairy plants found in several of the F_3 families.

The most convincing evidence of natural crossing comes from the F_3 generation grown from glabrous-chaffed, bearded F_2 plants of crosses between Iumillo or Kubanka with Marquis. Table III records the number of plants produced in different families as well as the number of bearded smooth, hairy, intermediate-awned, and intermediate-awned glabrous-chaffed plants. It is significant that all plants with hairy chaff had intermediate awns. This would be expected in the F_1 generation of a cross between bearded wheats and so-called awnless varieties such as Marquis or Bluestem. It is apparent that the amount of natural crossing varies in different families. For example, 196–26 produced 7 bearded, glabrous-chaffed plants and 7 intermediate-awned, hairy-chaffed plants, while family 214–35 produced 60 bearded plants.

The progeny of a few selected glabrous-chaffed, intermediate-awned F_2 plants of the cross between Marquis and durum are classified in Table IV. The parent F_2 sorts were classified as glabrous-chaffed, intermediate-awned. All such plants produced both bearded, awnless, and intermediate-awned plants in the F_3 generation. Numerous hairy-chaffed

plants were observed. None of these were bearded, all having either intermediate or very short-tipped awns like those of the Marquis parent. The evidence points to the conclusion that the hairy-chaffed plants obtained in the F_3 generation were the result of natural hybrids in the F_2 generation.

TABLE III.—*Number of hairy-chaffed intermediate-awned plants, glabrous-chaffed intermediate-awned plants, and glabrous-chaffed bearded plants in F_3 families grown from bearded glabrous-chaffed F_2 plants of crosses between Triticum durum and T. vulgare.*

Cross.	Number of plants.			
	Total.	Bearded, glabrous.	Intermediate-awned, hairy.	Intermediate-awned, glabrous.
Iumillo × Marquis:				
196-5	37	37	0	0
196-26	14	7	7	....
196-34	131	114	16	1
198-21	66	54	9	3
199-8	48	27	19	2
199-9	74	56	17	1
225-24	47	41	6	....
227-4	114	93	12	9
228-24	19	8	9	2
228-35	31	30	1	....
229-21	15	15	....	....
232-13	37	9	26	2
232-14	51	33	10	8
Average of 26 lines	381	302	73	6
Marquis × Kubanka (C I 2094):				
208-4	10	4	6	....
203-10	40	39	1	....
211-23	43	40	2	1
214-35	60	60	....	....
217-18	35	29	5	1
218-1	36	26	10	....
221-14	34	19	10	5
222-10	36	36	....	....
222-33	36	30	3	3
Average of 30 lines	495	412	54	29

TABLE IV.—*Number of hairy-chaffed plants and glabrous-chaffed plants in the F_3 families grown from intermediate-awned glabrous-chaffed F_2 plants of cross between Triticum vulgare and T. durum*

Plant No.	Number glabrous chaffed.	Number hairy-chaffed.
223-7	32	22
218-8	65	4
217-5	28	4
211-22	49	27
209-4	37	9
203-38	26	19
203-3	95	....
214-21	39	....

The fact that natural crossing often occurs in species crosses shows the necessity for caution in analyzing data;, and unless unusual methods are employed to protect parent plants, the ancestry of the progeny can not be known with certainty.

EXPERIMENTS IN INHERITANCE OF RUST RESISTANCE

The 1918 data are considered most reliable in drawing conclusions on the inheritance of rust resistance. This is due first to the fact that all barberry bushes were removed from the immediate vicinity of the rust plot early in the spring of 1918, and second to the fact that the epidemic was induced by hand spraying with inoculations of rust spores from a known greenhouse culture of *Puccinia graminis tritici*.[1]

RUST INFECTION OF THE F_1 GENERATION COMPARED WITH THAT OF PARENTS

The epidemic in the rust plots was satisfactory, although there was but little rust in other wheat fields on University Farm.

A considerable number of F_1 crosses between resistant durum and emmer wheats and Marquis, Preston, and Pioneer were grown in the rust plot. The percentages of stemrust infection on the F_1 and parent sorts are given in Table V.

TABLE V.—*Rust notes on parental varieties and F_1 crosses between resistant and susceptible wheats, 1918*

Variety or cross.	Percentage of stemrust.	Cross.	Percentage of stemrust.
Marquis	40 to 70	Marquis×Acme (C I 5284)	70
Preston	70	Preston×Acme (C I 5284)	70
Pioneer	40	Acme×Marquis	70
Acme	10	D-4×Pioneer	40
D-4	10	Acme×Preston	70
Kubanka (C I 2094)	20	Marquis×emmer	10
Iumillo (C I 1736)	15	Emmer×Marquis	10
Emmer (Minn. 1165)	0	Emmer×Preston	15
Marquis×Iumillo (C I 1736)	40	Preston×emmer	15
Marquis×Kubanka (C I 2094)	40 to 70		

Four durum varieties were tested. The highest percentage of rust infection was 20 on Kubanka (C I 2094), while there was only 10 per cent on D-4 and Acme. On all of these durum varieties the uredinia were smaller than on the common wheats, such as Marquis and Preston, which were very susceptible. Pioneer was also susceptible, but since it matures earlier than either Marquis or Preston, the percentage of infection was lower.

[1] The details of production of the epidemic were directed by J. G. Leach, a graduate student assistant of the Pathology Division. Mr. Leach had previous experience in this work at the Tennessee Agricultural Experiment Station.

The crosses between resistant durum wheats and Marquis, Preston, and Pioneer gave similar results, the F_1 generation being rusted as badly as the susceptible common wheat parent.

Different results were obtained in the F_1 crosses of emmer (Minnesota, 1165) with Marquis and Preston. The emmer parent is practically immune from this form of *Puccinia graminis tritici* as determined both by field data and experiments in the greenhouse. Two crosses, Marquis × emmer and Preston×emmer, and reciprocals were studied. While a few small uredinia developed on the F_1 generation, all plants observed were as free from rust as the resistant durum varieties. (See Pl. 97.)

That susceptibility is a dominant character in crosses between resistant durums and susceptible common wheats and a recessive character in crosses between resistant emmer and susceptible common wheats is obvious from these results. These facts bear out the observation made in the agronomy nursery in 1916—namely, that an F_1 cross between emmer (Minnesota 1165) and Marquis was resistant, while in an adjacent row an F_1 generation of a cross between a resistant durum and Marquis was severely infected.

CORRELATION BETWEEN RUST RESISTANCE AND BOTANICAL HEAD CHARACTERS

For the purpose of determining possible interrelation between inheritance of rust resistance and other differential characters, correlated individual plant data were taken on each F_2 plant.

DURUM-COMMON CROSSES.—Notes were taken on length of head, number of spikelets, breadth of head in face and side views, average length of internode, condition of awns, and rust infection on each individual F_2 plant. These plants were then classified into six groups—namely, emmerlike with seed inclosed by the glumes, durum, near-durum, intermediate, near-common, and common.

After the elimination of the emmerlike types the principal basis for classification was the appearance of the keel of the outer glume. In durum varieties the glumes are prominently and sharply keeled, while in the common wheats the outer glumes of the spikelets are only slightly keeled. The F_1 generation of a cross between durum and common wheats was intermediate for this character (Pl. 98). This one character determined whether the plant in question approached more closely the durum or the common type. The breadth of head in face and side views, the presence or absence of the depression in the center of the outer glume, and the condition of the collar were used in making the final classification. The depression is characteristic of common wheats. In most durum wheats the collar at the base of the lower spikelet extends all around the neck of the culm, while in common wheats it extends only part way around. Since progeny of the F_2 plants were grown in the F_3 generation, mistakes in classification were rectified. The individuals finally placed

in the durum, common, and emmer groups were those which bred true. Some of the near-durums may actually belong in the durum group, but there was no attempt to rectify unimportant mistakes in these classes.

The plants were placed in four rust infection groups: group 1, practically immune, 0 to 5 per cent infection; group 2, resistant, 10 to 20 per cent infection, uredinia smaller than in the normally susceptible varieties; group 3, susceptible, 25 to 40 per cent infection; and group 4, heavily infected. These groups were based on the behavior in the F_3 generation of the progeny of each F_2 plant.

In the F_2 generation some spikes with glumes resembling common wheat were as compact as those of the durum parents or more so. These were very similar to the club wheats and were placed in the common group. Likewise, lax-headed, sharply keeled wheats were obtained which were placed in the durum group. No differentiation was made between emmer and spelt, all plants with adherent glumes being placed together. Forms were obtained, however, which closely resembled true spelt.

The results from Marquis × Iumillo and Marquis × Kubanka were similar, and the data were combined. In the final summary in Table VI each plant is classified as resistant or susceptible. The writers believe that the plants classified as resistant would not be seriously injured in a severe epidemic of this rust form. However, there is considerable variation within each group. The resistant plants belong to either class 1 or 2 for rust infection.

There were two classes of susceptible F_2 plants, those which produced all susceptible progeny in the F_3 generation and those which produced both resistant and susceptible progeny. All resistant plants bred true in the F_3 generation; at least this was the criterion used to determine whether a particular F_2 plant was really resistant.

Several conclusions can readily be drawn from Table VI. This is a tabulation of 404 F_2 plants, each of which was tested in the F_3 generation. Of these 404 plants 4, 81, and 33 bred true to the botanical head type respectively of emmer, common, and durum. All 4 emmers and 8 out of 33 durums were resistant, while 81 F_2 common segregates were all susceptible. This strongly indicates that in these crosses resistance and susceptibility are linked in transmission with the botanical head characters which differentiate durum and common wheats. The results again show that it is easy to obtain resistant durums, while it is much more difficult, if not impossible, to obtain resistant common wheats.

As has already been mentioned, both lax and dense durumlike segregates (Pl. 99) as well as compact keelless common wheats were obtained. There seems, however, to be a relation between average length of internode and the botanical classes. Thus, the average mean head densities[1] of the five groups, durum, near-durum, intermediate,

[1] Density was calculated by dividing the length of the head in millimeters by the number of spikelets less one.

near-common, and common are 3.30, 3.77, 4.08, 3.94, and 4.40, respectively. A correlation coefficient of $+0.244 \pm 0.028$ for density and head characters was obtained.

TABLE VI.—F_2 *Marquis* × *Iumillo* (*CI 1736*) *and Marquis* × *Kubanka* (*CI 2094*)[1]

[R=resistant to stemrust. S=susceptible to stemrust]

Density.	Durum.		Near-durum.		Inter-mediate.		Near-common.		Common.		Emmer.	
	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.
Mm.												
2.5	3	4	2	12	.....	9	.....	12	.....	4	.....	.....
3.0	3	8	5	28	3	20	.....	16	.....	6	1	.....
3.5	2	5	2	29	6	19	.....	14	.....	12	3	.....
4.0	.....	4	6	22	2	26	1	19	.....	16	.....	.....
4.5	.....	4	3	20	2	21	.....	14	.....	10	.....	.....
5.0	.....	.....	.....	9	1	18	.....	7	.....	18	.....	.....
5.5	.....	.....	1	5	.....	9	.....	5	.....	6	.....	.....
6.0	.....	.....	.....	3	.....	8	1	6	.....	9	.....	.....
	8	25	19	128	14	130	2	93	0	81	4	0
Ratio	1:3.1		1:6.7		1:9.3		1:46.5		0:81		4:0	

[1] The coefficient of correlation between density of head and classes for durum, near-durum, intermediate, near-common, and common is $+0.244 \pm 0.028$.

F_2 generations in which the resistant durum parent was the female are given in Table VII, a total of 632 plants being classified on the basis of the F_3 breeding test. Of these F_2 plants 100 bred true to durum habit, 47 resembled common, while 3 were emmerlike. Sixteen out of 100 durumlike plants were resistant, while only 2 out of 47 classified as common were resistant. Of the three emmerlike plants, one was susceptible and the other two were resistant. Here, again, as with the reciprocal cross, there is an indication of linkage between common wheat head characters and susceptibility to stemrust. One intermediate susceptible F_2 plant was grown in the F_3 generation, and several plants were obtained with common head characters. One of these was very resistant and vigorous (Pl. 99).

The average densities of the durum, near-durum, intermediate, near-common, and common segregates were 3.76, 3.53, 4.06, 4.38, and 4.60, respectively, although both durum and common wheats were found in the extreme dense and lax groups. The coefficient of correlation between density and head type was $+0.330 \pm 0.024$.

In order to confirm field observations, a study was made in the greenhouse of the more resistant and susceptible durum, common, and emmer segregates obtained from the durum-common crosses. For head characters of types studied see Plate 101. Seedlings of F_3 plants were

inoculated with the form of *Puccinia graminis tritici* which was used in obtaining the field epidemic. Three different tests of resistant and susceptible segregates of emmer, common, and durum F_3 lines were made. The results are given in Table VIII. (See Pl. 102.)

TABLE VII.—F_2 *Iumillo (C I 1736)* × *Marquis and Kubanka (C I 2094)* × *Marquis*[1]

[R=resistant to stemrust. S=susceptible to stemrust]

Density.	Durum.		Near-durum.		Intermediate.		Near-common.		Common.		Emmer.	
	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.
Mm.												
2.5	1	7	4	19	2	11	.....	2	.....	3	1	.....
3.0	8	24	11	40	.....	22	2	15	.....	2	.....	1
3.5	3	18	6	27	2	30	1	8	1	6	.....	.....
4.0	2	7	3	22	2	47	1	24	.....	6	.....	.....
4.5	.....	10	1	19	2	43	1	21	.....	7	.....	.....
5.0	1	13	1	9	.....	31	.....	16	.....	6	1	.....
5.5	.....	2	.....	2	.....	2	.....	20	1	6	.....	.....
6.0	1	3	.....	1	.....	6	.....	6	.....	9	.....	.....
	16	84	26	139	8	192	5	112	2	45	2	1
Ratio	1:5.3		1:5.3		1:24.0		1:22.4		1:22.5		1:0.5	

[1] The coefficient of correlation between density and type as durum, near-durum, intermediate, near-common, and common is +0.330 ±0.024.

TABLE VIII.—*Comparison of resistant and susceptible F_3 lines with Marquis, Kubanka (C I 2094), and Iumillo (C I 1736)*[1]

Source.	Plant No.	Type.	Number inoculated.	Number infected.	Remarks.
Marquis	Minn. 1239	Common	10	10	Extremely susceptible.
Kubanka	C I 2094	Durum	12	10	Moderately susceptible with slight chlorosis under infected areas.
Kubanka × Marquis F3	222-32	Emmer	18	8	Extremely resistant; uredinia minute, surrounded by sharp hypersensitive areas; 8 plants were strongly flecked.
Kubanka × Marquis F3	222-30	do	11	10	Highly susceptible; infection normal.
Iumillo × Marquis F3	181-24	Common	14	12	Highly susceptible; infection normal.
Iumillo × Marquis F3	186-13-5	do	21	4	Infection moderate with slight chlorosis under infected areas; 7 plants were strongly flecked.
Iumillo × Marquis F3	228-37	Durum	17	8	Moderately resistant with chlorosis under infected areas; 2 plants were distinctly flecked.
Iumillo × Marquis F3	186-15	do	20	19	Highly susceptible; infection normal.
Iumillo	C I 1736	do	22	11	Slightly susceptible; 4 plants were distinctly flecked with slight chlorosis under some infected areas.

[1] The authors wish to express their thanks to M. N. Levine, Assistant Pathologist, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, for preparing Table VIII and Plate 101 and for conducting the greenhouse experiment on which they are based.

These families were selected in the field as examples of resistant and susceptible F_3 lines. Since the inoculation results in the greenhouse corroborate the field observations, there is good reason for believing that the field observations are reliable. This greenhouse experiment shows clearly that transgressive segregation occurred. Common, durum, and emmer sorts were obtained with a higher degree of resistance than that of either of the durum parents.

These results show that, if the numbers are sufficiently large, it is possible to obtain resistant wheats with common head characters by crossing resistant durum and susceptible common varieties. In the F_2 generation, out of a total of 128 common segregates only 2 were rust-resistant, and both of these were of little commercial value. However, several resistant plants with the head characters of common wheats were obtained in the F_3 generation.

EMMER-COMMON CROSSES.—Only a few plants were available for the study of crosses between emmer and common varieties. Two different white spring emmers (Minnesota 1165 and C I 1524) were used in this study. Minnesota 1165 is a very vigorous variety which was practically immune from the form of stemrust experimented with, both in the field and in the greenhouse. C I 1524 is quite similar to Minnesota 1165, except that it occasionally produces small uredinia.

The difference between emmer and common wheat is greater than that between durum and common wheat. The shape of the head of the emmer parent, which is proportionally very narrow in face view, together with the strongly keeled glumes, differentiates it from the Marquis parent. The kernels of emmer are tightly inclosed by the glumes, and recognition is easy.

The F_1 generation of the cross between emmer and common is intermediate for the differential characters mentioned above as separating the parent sorts (Pl. 98). The keels of the F_1 generation are intermediate, but they more closely resemble those of the emmer parent. The head shape of the F_1 generation is likewise more nearly emmerlike. Fifty-six per cent of the kernels were naked and 44 per cent had adherent glumes after they were thrashed in an individual plant thrasher. The emmer parent produced 19 per cent naked kernels and 81 per cent hulled kernels. The F_1 generation (Table V) is nearly as resistant as the emmer parent. Thus, the F_1 generation more nearly resembles emmer.

Fifty F_2 plants of the cross between Marquis and emmer (Minnesota 1165) were grown in the F_3 generation. Of this number 5 plants were emmers, and 1 was a very susceptible, lax, common type. The progeny of 5 F_2 plants thrashed like common wheats in the F_3 generation, but the heads were very compact (Pl. 100). Two F_2 plants bred true to the common keel condition and segregated, producing compact, intermediate,

and lax heads. Thirty-seven produced progeny consisting of types with inclosed emmerlike kernels, intermediates for thrashing, and common plants. Of these 37 F_3 lines, 17 produced progeny of only two sorts, emmerlike for thrashing and compact keelless (Pl. 100).

It is, of course, impossible to determine the actual factors involved in this cross, because some gametes or zygotes were eliminated by sterility.

The cross in which emmer (C I 1524) was the female parent gave results similar to those obtained when emmer was used as the male parent. This is shown in Table IX. One family, 169-5, which was grown from an intermediate F_2 plant, produced emmers, intermediates, and common-headed sorts and was quite resistant (Pl. 100).

TABLE IX.—*Classification of crosses between emmer (Minnesota 1165 and C I 1524) with Marquis on the basis of rust class in the F_2 generation as determined by the F_2 and F_3 generations, and the main character differences separating emmer from common wheats as determined by the F_2 and F_3 generations*

MARQUIS × EMMER 1165

Rust class.	Emmer.	Segregating emmer to common.	With nonadherent glumes.			Total.
			Compact.	Segregating.	Common.	
1	4	9	1	1	....	15
2	1	21	....	....	....	22
3	....	7	4	1	1	13
Total	5	37	5	2	1	50

EMMER (C I 1524) × MARQUIS

Rust class.	Emmer.	Segregating emmer to common.	With nonadherent glumes.		Total.
			Compact.	Segregating.	
1	3	3	4	....	10
2	....	6	2	1	9
3	....	2	2	....	4
Total	3	11	8	1	23

It is interesting that out of a total of 73 plants from these two crosses, 8 bred true to the emmer habit for thrashing and for head shape. Of these 8, 7 plants were put in rust class 1 while 1 was practically resistant, the progeny in the F_3 generation being placed in rust class 2. Only one lax, common plant was obtained in the F_2 generation, and this was susceptible. Several plants were obtained in the F_3 generation which were not only rust-resistant but also resembled common wheat.

These facts show that it is possible to transfer the rust resistance of emmer wheats to common wheats by crossing and subsequent selection. There is, however, an apparent partial linkage between rust resistance and the emmer head type which makes it essential to grow large numbers in the F_2 and F_3 generations.

SUMMARY

(1) Recent studies of the parasitism of the black stemrust of wheat (*16*, *18*, *21*, *24*) have shown that there are many biologic forms of *Puccinia graminis* which can be differentiated only by their action on pure line wheat hosts. This seriously complicates the breeding of wheat for rust resistance. In the light of this knowledge differences of infection of certain crosses in 1917, as compared with 1916 or 1918, show that the conflicting results may be explained logically by supposing that more than one biologic form was present in the rust nursery in 1917.

(2) Sterility is a factor which must be considered in a study of crosses between common wheats and durum or emmer varieties. Sterility was shown in three ways: (a) pollen abortion; (b) the fact that F_1 florets of durum-common crosses set nearly 50 per cent less kernels than the parent sorts, while F_1 emmer-common crosses produced about 25 per cent of barren florets; and (c) the large number of natural crosses which occurred in some F_2 plants as shown by the F_3 results.

(3) Crosses between durum and common wheats produced many different forms in the F_2 generation, such as compact keelless commons resembling club wheats, lax sharply keeled durums, both emmer and spelt, as well as types which resembled the poulard group. Lax and compact durum, common, and emmerlike forms were obtained which bred true in the F_3 generation. The segregation in the F_2 generation of emmer-common crosses was not so wide as in the durum-common cross, although both lax and compact keelless wheats which bore naked kernels, as well as lax and compact wheats with adherent-glumed kernels, were obtained.

(4) The study of inheritance of rust resistance was made in a specially prepared disease plot. Because of the conflicting results of 1916 and 1917 all barberry bushes were removed early in the spring of 1918 from the immediate vicinity of the rust plot and the epidemic was induced with a known form of rust. The data on rust infection are based on these 1918 results.

(5) The following species and varieties were used in the study: *Triticum vulgare*, varieties Preston, Marquis, and Pioneer; *Triticum durum*, varieties Acme, D-4, Kubanka (C I 2094), and Iumillo (C I 1736); *Triticum dicoccum*, White Spring emmer (Minnesota 1165 and C I 1524).

The three common wheats were susceptible, the durums were commerically resistant, Kubanka (C I 2094) being somehwat less resistant

than Iumillo (C I 1736), while Acme and D-4 were slightly more resistant than either of the other durum sorts. The emmer varieties were very resistant, Minnesota 1165 being practically immune.

(6) The F_1 generation of crosses between durum and common varieties was as susceptible as the common parent, while F_1 crosses between the practically immune emmer parents and susceptible commons were about as resistant as the durum varieties. Thus, in the cross where emmer is one parent, resistance is partially dominant, while in the durum-common cross susceptibility is completely dominant over resistance.

(7) Each F_2 plant which produced viable seed was tested in the F_3 generation for both rust infection and botanical characters. These F_3 notes were used to determine the genotypic nature of individual F_2 plants. In the crosses between durum and common in which Marquis was the female parent, 404 F_2 plants were tested in the F_3 generation and no rust-resistant common wheats were obtained. Likewise, no plants in the F_3 generation seemed especially promising for both common wheat characters and rust resistance. In the crosses in which durum was the female, one or two F_2 common-headed plants were resistant; but their progeny were worthless from a practical agronomic standpoint. In one F_3 family which was grown from a susceptible F_2 plant, a number of resistant, vigorous plants were obtained which had common head characters. There is an indication of linkage of durum or emmer characters and rust resistance, since the production of rust-resistant durums or emmers in the F_2 and F_3 generations is comparatively easy and the production of resistant common wheats much more difficult.

(8) Resistant and susceptible plants obtained either in the F_2 or F_3 generation from crosses of durum and common parents were selected. Resistant and susceptible common, emmer, and durum wheats were available for this study. Greenhouse inoculation studies with a known strain of *Puccinia graminis tritici* showed that durum, common, and emmer type plants were obtained in the F_2 or F_3 generation which were more resistant than the resistant durum parents. Thus, we have transgressive segregation for rust resistance.

(9) The number of plants available for a study of inheritance between resistant emmer parents and Marquis was not very great. In the F_3 generation several lax-headed wheats were obtained which had the head shape and naked kernels of common wheats and which were rust-resistant. This shows that rust-resistant common wheats can be obtained by crossing susceptible common varieties with resistant emmers.

(10) The mode of inheritance of rust resistance seems entirely comparable with the general Mendelian manner of inheritance of botanical and morphological characters. The technic of breeding for rust resistance is similar to that of breeding for agronomic characters.

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PLATE 97.

A.—Pollen grains of Marquis wheat.

B.—F_1 Marquis×Kubanka (C I 2094), showing sterile grains.

C.—Pollen grains of Kubanka (C I 2094).

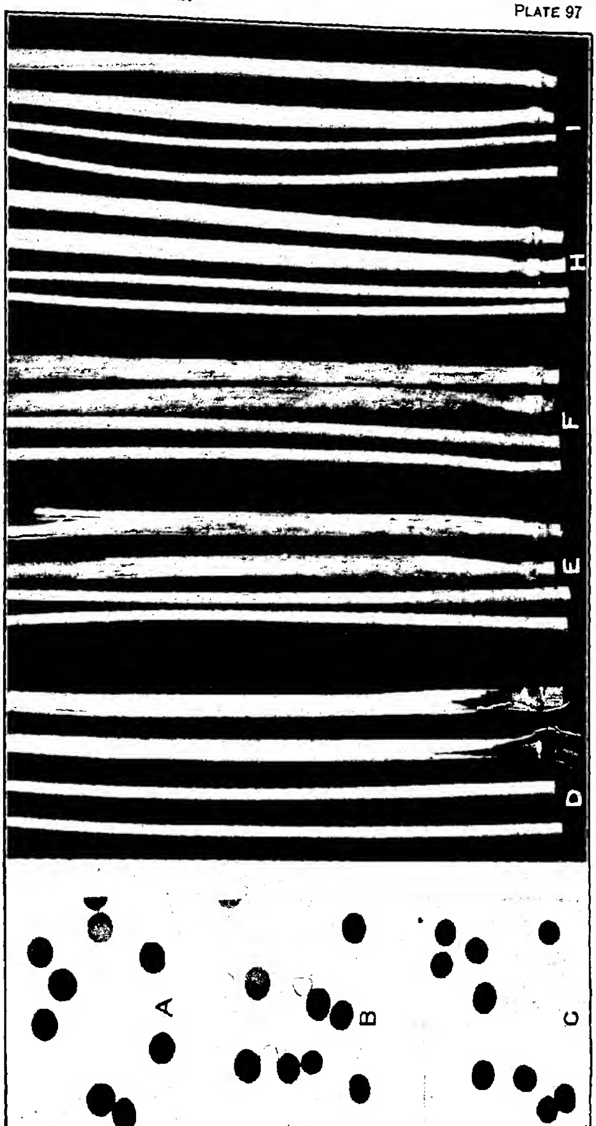
D.—Stems of Kubanka (C I 2094) grown under rust-epidemic conditions. Note absence of rust infection.

E.—F_1 Kubanka (C I 2094)×Marquis, showing normal uredinia.

F.—Marquis, the susceptible parent.

H.—F_1 emmer (Minnesota 1165)×Marquis, showing no normal uredinia.

I.—Minnesota 1165, the resistant emmer parent. Note that in the durum-common cross the F_1 generation is susceptible while in the emmer-common cross the F_1 generation is resistant.


I
H
F
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D
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B
C


A
B
C
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G
H
I

PLATE 98.

A, B, C.—Face and side views, respectively, of heads of Iumillo (C I 1736), F_1 Iumillo × Marquis, and Marquis. The F_1 heads are intermediate in density and have tipped awns. The outer glumes are keeled, although not so strongly as Iumillo.

D, E, F.—Face and side views, respectively, of heads of emmer, Minnesota 1165, F_1 emmer × Marquis, and Marquis. The F_1 generation approaches the emmer in some head characters and has intermediate awns.

G, H, I.—Kernels of Marquis, F_1 emmer × Marquis, and emmer. The F_1 kernels are longer than Marquis, approaching those of the emmer parent in average length.

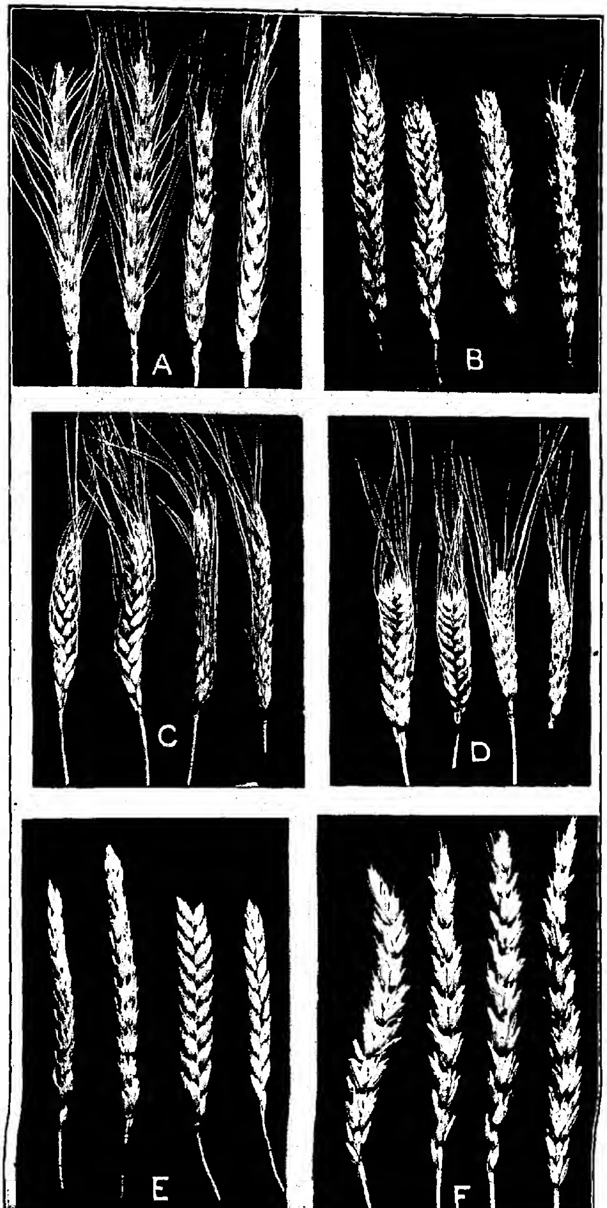
PLATE 99.

Representative heads of F_3 families of the cross between durum and Marquis.

A, B, C, D.—F_3 families which were classified as durums. Note that these represent all types of head density.

E.—Heads of an awnless F_3 emmer family.

F.—Four heads of an F_3 plant which resembles common wheat in head shape and is rust-resistant.


A
B
C
D
E
F

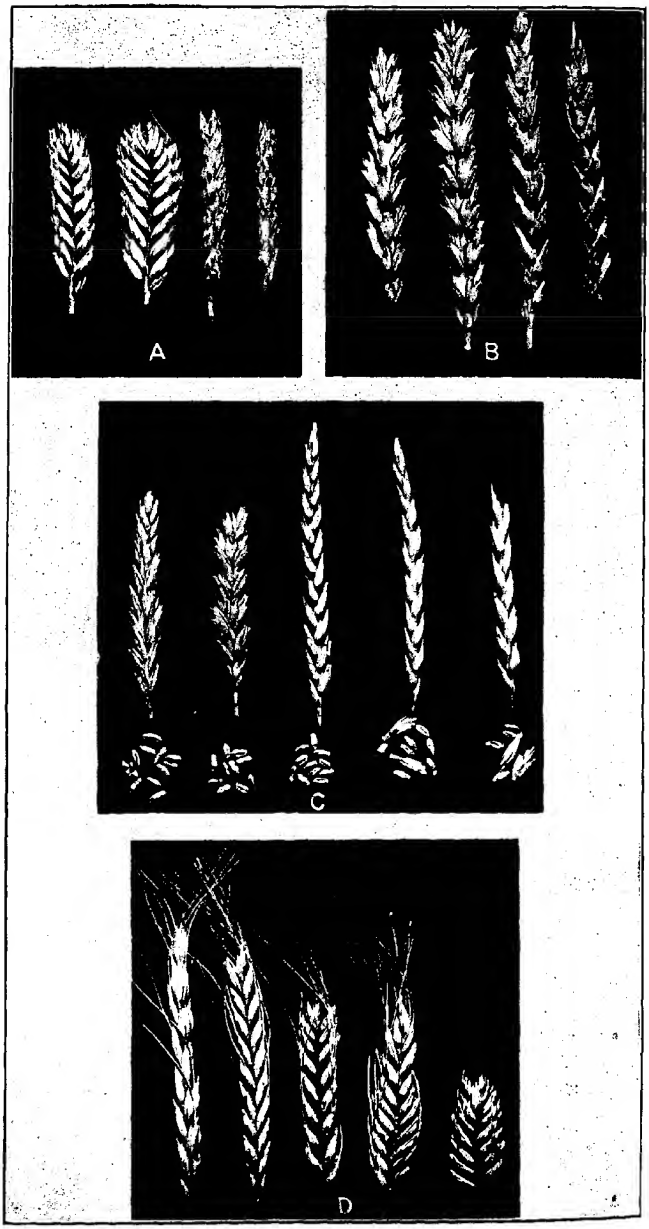

A
B
C
D

PLATE 100.

A.—F_3 family of a cross between emmer (Minnesota 1165), and Marquis, showing face and side view. This family proved rust-resistant and was also pure for keelless, compact heads and thrashed like common wheat.

B.—Heads of an F_3 family which resembled common wheat. It was rust-susceptible.

C.—Heads of different plants of an F_3 family of a cross between emmer (C I 1524) and Marquis. The plants varied from emmerlike and intermediate forms to those resembling common wheat as shown at the left. This family bred true for rust resistance.

D.—Represents a very frequent sort of segregation obtained in the F_3 generation. Many families gave only emmerlike and keelless, compact headed sorts which thrashed like common wheat.

PLATE 101.

Heads of resistant and susceptible wheat obtained in the F_3 generation from the cross between Marquis and durum:

A.—Head representing resistant emmer type F_3 family 222-32, Kubanka × Marquis.

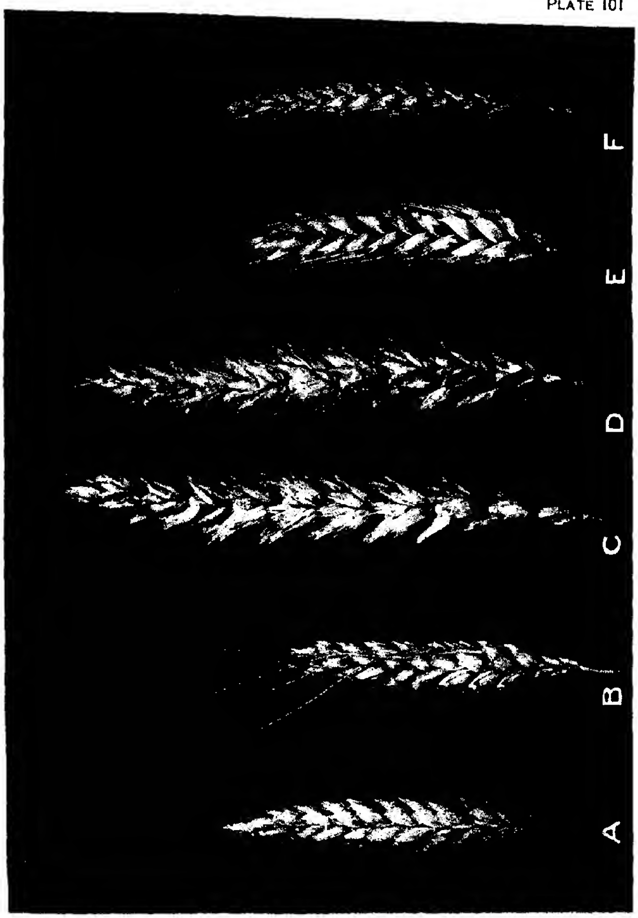
B.—Head representing susceptible emmer F_3 family 222-30, Kubanka × Marquis.

C.—Susceptible common F_3 family 181-24, Iumillo × Marquis.

D.—Resistant individual plant 186-13-5 which was obtained in the F_3 generation of the cross between Iumillo × Marquis.

E.—Resistant durum F_3 family 228-37, Iumillo × Marquis.

F.—Susceptible durum F_3 family 186-15, Marquis × Iumillo.


A
B
C
D
E
F

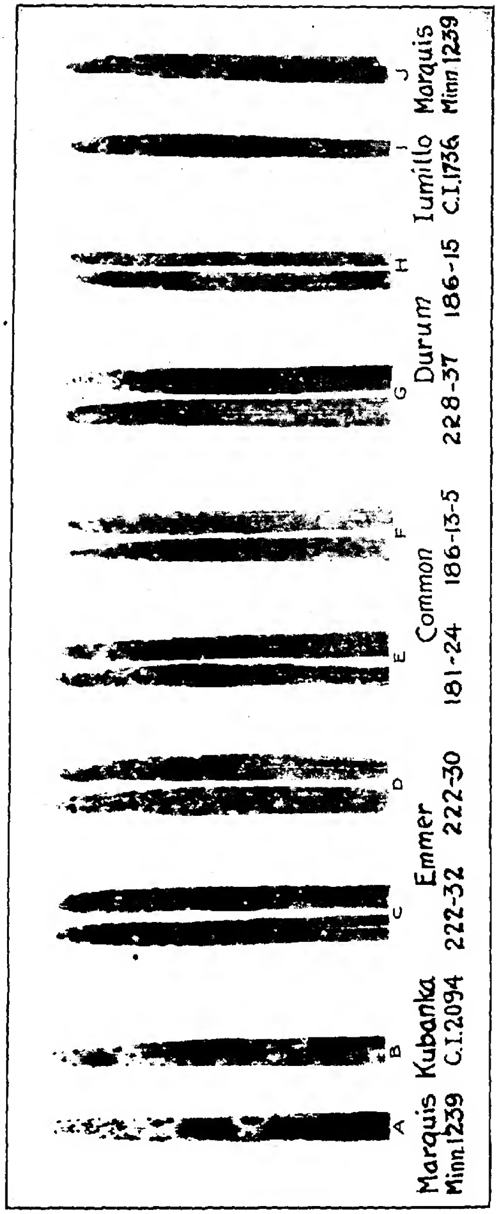

A Marquis Minn.1239
B Kubanka C.I.2094
C Emmer 222-32
D 222-30
E Common 181-24
F 186-13-5
G Durum 228-37
H 186-15
I Iumillo C.I.1736
J Marquis Minn.1239

PLATE 102.

Greenhouse experiment:

A.—Marquis, single blade, showing extreme susceptibility.

B.—Kubanka (C I 2094), single blade; moderately susceptible with slight chlorosis.

C.—Kubanka × Marquis (222-32 F_3 emmerlike family); extremely resistant; uredinia minute surrounded by hypersensitive areas, or flecks.

D.—Kubanka × Marquis (222-30 F_3 emmerlike family); very susceptible.

E.—Iumillo × Marquis (181-24 F_3 common family); very susceptible.

F.—Iumillo × Marquis (186-13-5, an individual common plant of F_3 family 186-13); moderately resistant with infected areas chlorotic.

G.—Iumillo × Marquis (228-37 F_3 durum family); moderately resistant with infected areas chlorotic.

H.—Iumillo × Marquis (186-15 F_3 durum family); fairly susceptible.

I.—Iumillo (C I 1736), single blade; slightly susceptible.

J.—Marquis (Minnesota 1239), single blade; highly susceptible.

The rust form used in the greenhouse experiment was the same as that used for the 1918 field epidemic.

LINE-SELECTION WORK WITH POTATOES

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The data and discussions presented here have to do with the subject of potato-seed improvement through tuber selection. As such it deals with the improvement of existing varieties and may be contrasted with another type of potato breeding which, through the mediums of fertilization, production of seed, and growing of seedlings, aims at the origin of new varieties.

In the language of the plant breeder potato varieties are termed clons or clonal varieties. To him they differ from varieties of wheat, barley, or corn in that they are propagated from vegetative parts. Sexual reproduction or the use of seeds is resorted to only as a means of originating new varieties, not as a means of perpetuating existing ones. Varieties of wheat, barley, or corn reproduce true from seed, while clonal varieties do not. In other words, if we plant pure seed of yellow corn or blue barley, we harvest yellow corn or blue barley, but if we should plant seeds of red apples or red potatoes it is very doubtful if we should harvest either red apples or red potatoes. Few, if any, will doubt the value of potato-breeding work which has for its object the origin of new varieties from seed. Most of our potato varieties have originated as seedlings, either chance seedlings or those resulting from carefully planned breeding work. This phase of potato breeding is still attracting the attention of both scientific and amateur plant breeders, and new seedlings are constantly being introduced for trial. Some of these are real additions to potato culture, and others prove of only local and passing interest.

The improvement of clonal varieties through bud selection has been the subject of much discussion and the basis for much experimental study. In propagation, the horticulturist deals largely with clons or varieties which must be perpetuated by transplanting vegetative parts. Fruit trees, small fruits, many ornamental plants, nut trees, bulbous and tuberous plants, and many flowers, particularly greenhouse specialties, fall in this class. This line of plant breeding is of just as vital importance as the other which aims at improvement through crossing and hybridization and the growing of new seedlings. Potatoes have been the subject of much study along this line, the work of East,[1] Eustace,[2]

[1] East, Edward M. A study of the factors influencing the improvement of the potato. Ill. Agr. Exp. Sta. Bul. 127, p. 375-456, 10 fig. 1908. Bibliography, p. 450-456.

—— The transmission of variations in the potato in asexual reproduction. *In* Conn. Agr. Exp. Sta. Rpt. 1909/10, p. 119-160, 5 pl. 1910.

[2] Eustace, H. J. An experiment on the selection of "seed" potatoes: productive vs. unproductive hills. *In* Proc. Soc. Hort. Sci., 1903/04, p. 60-62. 1905.

Journal of Agricultural Research, Washington, D. C.
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Vol. XIX, No. 11
Sept. 1, 1920
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Waid,[1] and Zavitz[2] being the most important of that reported in America. It is safe to say, however, that the work done so far has not by any means cleared up the subject of selection within clonal varieties. At present we can not say that we have a clear vision of the possibilities or the limitations along this line of plant breeding. Since plants within clonal varieties vary, we have assumed that there is opportunity for improvement through selection just as in varieties that are propagated from seed. But to what extent we can make use of selection to perpetuate desirable variations within the clon and in this way improve these varieties is still a question.

The plant breeder recognizes in plants three types of variations: (1) fluctuations or modifications, (2) segregations or combinations, and (3) mutations. Fluctuations are such variations as appear as a result of variable environmental conditions and are by many considered nonheritable or nontransmittable from one generation to another, regardless of whether perpetuation is through seeds or vegetative parts. In other words, if we accept this theory of the nonheritability of fluctuations due to environment we can not expect to increase the average vigor of a potato variety by selecting seed tubers from especially vigorous hills so long as the variation in vigor might be attributed to environmental conditions. Segregations are heritable differences resulting from segregation and recombination of hereditary units. This type of variation appears within the population of new hybrids and crosses perpetuated by seeds rather than by vegetative multiplication. Among potatoes we could expect such variations to appear only among seedlings, and for this reason segregation can not be considered among the possibilities for improving potato varieties which are perpetuated vegetatively. Mutations are heritable variations which do not depend upon segregation and recombination. Mutations are supposed to be much rarer than the other variations mentioned. Among horticultural plants many clonal varieties have arisen in this way and have for many years been perpetuated true to type through vegetative multiplication. An excellent example of a mutant among potatoes is the Pearl, which originated as a mutation, or in common language, as a bud sport from the Blue Victor. This has occurred not only once but several times. In our own Blue Victor seed plot of 1918 there appeared such a variation. This mutant was a perfect Blue Victor with the exception that it was white instead of blue in color. In other words, it was a perfect Pearl. In this seed plot, seed pieces from each tuber were planted in consecutive hills. The hills were thinned to single stems, and just one

[1] GREEN, W. J., and WAID, C. W. POTATO INVESTIGATIONS. SPRAYING AND SEED SELECTION EXPERIMENTS; VARIETY TESTS. Ohio Agr. Exp. Sta. Bul. 174, p. 251-289, 18 fig. 1906.

WAID, C. W. RESULTS OF HILL SELECTION OF SEED POTATOES. *In* Amer. Breeders' Assoc. Rpt., v. 3, p. 191-199. 1907.

[2] ZAVITZ, C. A. [REPORT OF THE DEPARTMENT OF FIELD HUSBANDRY.] *In* 31st Ann. Rpt. Ontario Agr. Exp. Col. and Exp. Farm, 1905, p. 165-220. 1905.

plant appeared with white potatoes. This means that one eye from a typical Blue Victor tuber produced a plant which bore white potatoes while all other eyes from the same tuber produced plants with blue potatoes true tq type. This hill of white potatoes will, if planted, give plants bearing only white potatoes, for these simple bud sports or simple vegetative mutants may be perpetuated by propagation from vegetative parts. Here, then, we have an excellent example of how new varieties appear by mutation, but apparently such bud sports do not appear frequently.

If we purpose to champion the cause of selection within potato clons we must either show that high-yielding mutants, less striking than the one just mentioned and possibly for this reason more often unobserved, frequently appear within the clon and form the basis for selection, or we must break down, so far as clonal varieties are concerned, the theory that all fluctuations, or modifications are nonheritable. The greater part of the data here presented is the result of work begun with the intent of throwing light upon the first question. Experiments are also under way bearing upon the heritability of fluctuations, but as yet the data are not sufficient to warrant publication.

No one, I think, will doubt the value of certain lines of potato seed-selection work. For instance, there is abundant evidence to show that under anything like favorable environmental conditions the yielding power of a variety may be maintained by careful selection. In other words, a system of seed-tuber production which aims at the annual elimination of diseased or degenerate hills will, except under the most unfavorable environmental conditions, maintain a high-yielding population of any variety. But aside from the elimination of these weak hills we may question whether any practical results will come from further effort. In this case we are eliminating the hills that are below the average in vigor, the loss of vigor being due to attacks of disease or to degeneration. A very satisfactory method of procedure in such selection efforts is well outlined in Circular 73 of this Station.[1] The extent to which yields are increased by such selection is largely determined by the stock started with, its susceptibility to disease, and the tendency of the particular variety to degeneration under existing climatic and soil conditions. Starting with a variety population containing a large percentage of degenerate or diseased plants, proper selection will bring about a marked increase in yield. In growing a variety that has degenerrate tendencies under certain environmental conditions, such a system of selection will be found very helpful in maintaining the yielding power of the variety. For the purpose of illustration, some examples may be cited. Russet Burbank, as it has been grown at Bozeman, is a very stable variety. Very few diseased hills appear in the plots, and very

[1] Whipple, O. B., A seed plot method of potato improvement. Mont. Agr. Exp. Sta. Circ. 73, p. 71-73. 1917.

few degenerate plants are found. Irish Cobbler and Early Triumph have behaved in just the opposite way, at least so far as degeneration is concerned. Within the last two varieties, as grown under our conditions, intelligent selection will give surprising results. With the Russet Burbank, profitable increase in yield might result from selection, but the improvement would be in no way spectacular. This type of selection work aims at increased production through the elimination of plants yielding below the average of the population.

The first work in line selection was undertaken in 1913 with the selection from the crop of that year of a few high-yielding hills of Russet Burbank (hills 201 to 206) and Rural New Yorker (hills 207 to 212). These have now been tested for five years, and a summary of the results is given in Table I. While these data do not represent a very large amount of experimental evidence, I believe that the results indicate what can be expected when effort is made to isolate high-yielding clonal lines by hill selection and maintain them by mass selection based upon tuber characteristics. Every effort was made to eliminate experimental errors. Seed pieces were dropped 15 inches apart in rows 3 feet 9 inches apart. Single-row plots were used with outside or guard rows in every case. In 1914, these plots were necessarily small. In 1915, 1/40-acre plots were used, and since 1915 plots of approximately 1/20-acre have been grown. No special effort has been made to control the size of the seed piece; but in 1914, 1915, and 1916 the plots were thinned to single-stemmed hills. This method gives promise of being as reliable as one based on the planting of uniform-sized seed pieces, for size of seed piece appears to influence yield only in so far as it is correlated with the number of stems produced in the hill. In other years the size of seed pieces could not have varied greatly, since the plan of cutting tubers of certain sizes to so many seed pieces was followed, without reference to number of eyes. The hills selected in 1913 were single-stemmed hills and were chosen on yield and tuber characteristics entirely. Of a large number of hills dug with a fork, those were selected which gave the greatest weight of tubers of good form. Tubers considered of good form were those long for the variety, full and rounded at both ends, and oval rather than round in cross section. In choosing seed by mass selection, the same form characteristics were considered; and the seed was picked after the digger. The seed for control plots was chosen by mass selection from the population of the variety from which the hills originally came, selection being based upon the same tuber characteristics. Single-plot tests were employed.

In Table I, I wish to call attention not so much to the 5-year performance record of the hill lines as to the very marked variation between their yields in 1914 and 1915 when compared with the control plots. If we take the 5-year average as a reliable indicator, some of these lines are apparently better yielders than others. I believe, however, that an-

other 5 years added to these performance records will go a long way toward blotting out these apparent differences. It will be noted that all these hills gave a very large increase over the control plots in 1914. But the interesting feature of the records is that following mass selection in 1914, the average yield of these lines immediately falls, in 1915, to the level of that of the control plot. In this connection it should be borne in mind that these two varieties are very stable under conditions at the Station and that neither has shown any serious tendency toward degeneration. The increased production in 1914 can not be accounted for on the theory that degenerate or weak hills were common in the control plots in 1914, nor can the decrease in yield in 1915 be accounted for on the theory that mass selection introduced into these lines degenerate types which tended to lower the yield of 1915. I believe the data clearly indicate that hill selection brings only temporary increases in yield and that such selection does not isolate high-yielding lines which may be maintained as high-yielding population by mass selection based on tuber characteristics alone.

TABLE I.—*Five-year summary of yields of marketable tubers per acre from hills selected in 1913*

Hill No.	1914	1915	1916	1917	1918	5-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
201	14, 764	13, 350	8, 552	23, 580	10, 849	14, 219
202	19, 446	12, 461	7, 456	20, 537	13, 497	14, 579
203	18, 409	12, 543	8, 880	23, 394	13, 660	15, 377
204	19, 924	10, 930	8, 515	23, 464	13, 033	15, 173
205	18, 207	12, 947	7, 572	18, 724	10, 756	13, 641
206	13, 839	11, 898	7, 744	18, 353	....	12, 958
Average	17, 431	12, 354	8, 119	21, 342	12, 359	14, 341
Control	11, 836	12, 947	8, 766	19, 143	17, 424	14, 023
207	14, 157	11, 823	7, 509	21, 675	14, 961	14, 025
208	12, 251	14, 278	5, 406	19, 514	16, 425	13, 574
209	18, 513	9, 873	6, 969	22, 511	20, 490	15, 671
210	17, 936	8, 566	6, 218	20, 932	15, 007	13, 731
211	17, 616	8, 826	....	16, 090	21, 141	15, 918
212	18, 315	7, 700	....	20, 328	11, 685	14, 507
Average	16, 464	10, 177	6, 525	20, 175	16, 618	14, 571
Control	10, 257	9, 961	6, 069	20, 165	17, 214	12, 733

In 1916 work of similar nature was undertaken upon a more extended scale. With the selection of 108 tuber units each of Green Mountain, Rural New Yorker, and Early Six Weeks, 324 tuber lines were established, which have now been carried through three seasons. Eight of these lines were thrown out from the Early Six Weeks as variety mixtures, most of the 8 being Early Rose, so the summary on this variety covers only 100 tuber lines. Rural New Yorker has been previously referred to as quite

stable. Green Mountain, as grown at Bozeman, has rather strong degenerate tendencies, but Early Six Weeks would be classed as almost as stable as Rural New Yorker, since no rapid decline in yield followed selection based upon tuber characteristics. Since in this work every effort has been made to overcome the possibility of error, a discussion of methods will be in order.

Tuber units were selected from the bin in the spring of 1916. In each variety these tubers were cut to a uniform weight by slicing off the stem end. The Green Mountain tubers were cut to 7 ounces, the Rural New Yorker to 8¾ ounces, and the Early Six Weeks to 6½ ounces. The remaining portion of the tuber was then quartered lengthwise. Since 1916 seed pieces have been cut with a special cutter which cuts a seed piece approximately hemisperical in shape, 1¼ inches across the face and ¾ inch deep. Such seed pieces weigh approximately ⅓ ounce, or about 11 gm. Because of variation in depth of eyes, these seed pieces will differ somewhat in weight, the maximum variation within a variety usually not exceeding 2 gm. and in many cases not exceeding 1 gm. Groups of 20 seed pieces seldom show variation of over 15 gm. While these seed pieces may appear small, they have apparently given just as strong plants as seed pieces cut in the usual manner and weighing 1½ ounces. Seed pieces have been planted by hand and covered to a uniform depth of 3 inches. Single-plot tests have been used entirely. Such tests carried on over a series of years should give just as reliable results as duplicate or triplicate tests conducted for a shorter period. Duplicating plots complicates the work of seed selection. It is not safe to select seed from any one plot to continue the line the following season, and it is difficult to select a small composite sample from two or three plots. It is for this reason that the single-plot test was decided upon.

The 1916 plots consisted of 4 hills, and the 1917 and 1918 plots of 20 hills. The latter is the standard-sized plot adopted here for this work. The selections from each variety are arranged in a group with from 9 to 12 plots in a row and from 9 to 12 rows. There is no space between plots in the rows. The control plot consists of a single row near the center of the group running the length of the group of plots. Hills are planted 15 inches apart in rows 3 feet 9 inches apart. Seed is chosen from the plots before the tubers are assembled, and in this way it is secured from different portions of the plot. To illustrate, from a standard-sized plot 5 seed tubers are selected. Four seed pieces from each tuber are planted the following season in adjacent hills, and when this crop is harvested, effort is made to select one seed tuber from each group of four hills, or from each unit, as they are called later. The plots receive rather deep cultivation, are well ridged, and are commonly irrigated once. At any rate they all receive the same cultivation and irrigation. All hills are thinned to single stems as soon as the vines are strong enough to pull, or from five to six weeks after planting.

Since these small seed pieces give an average of only about 1½ stems per hill, the thinning is not a very great task. Careful records are kept of the number and weight of marketable tubers and culls. Yields are computed upon the basis of a perfect stand. Naturally this favors the plot with an imperfect stand, for a missing hill tends to raise the yield of adjacent hills. Stand records are kept, showing the position of missing hills. As yet there is no basis upon which to apply such records in correcting yields, but I hope to make use of these later. Careful notes are also kept upon vine characteristics. We are particularly interested in those that indicate degeneration. Three general types of vines—vigorous, semi-curlydwarf or with curlydwarf tendencies, and curlydwarfs—are recognized.

The results of three seasons' work upon this project are presented here, not with the idea of proving the presence or the absence of high-yielding tuber lines within these 316 selections but rather for the purpose of calling attention to the difficulty of interpreting these performance records. If such a method of seed improvement is to be of real and practical value, especially in the hands of the average potato grower, it would seem that a 3-year test should give rather definite and dependable results. If the process is to be a longer one than this, then the method should be proposed for the potato specialist rather than for the rank and file of potato growers.

GREEN MOUNTAIN TUBER LINES 300 TO 408

In variety tests at this Station, the Green Mountain types have on an average given the highest yields of all varieties grown. Varieties belonging to this group have, however, varied rather widely in yields. They are more susceptible to scab, more inclined to degeneration, and produce tubers less desirable as to commercial form than the Rural New Yorker; but withal the type is a very promising main-crop commercial potato.

In Table II will be found the 3-year performance records of the 108 Green Mountain lines, expressed in yields of pounds per acre. Of the three groups of tuber lines, these have given the most noticeable variations in yields.

Line 332 ranks first with a 3-year average yield of 27,849 pounds per acre, while line 344 has a 3-year average of 3,841 pounds. When ranked on 3-year average tuber production by weight, the 20 highest-yielding lines assembled in the last column of Table III have given an average yield of 25,000 pounds per acre, while the 20 lowest-ranking, appearing in the last column of Table IV, have averaged 12,083 pounds.

In Tables III and IV it will be noticed that only a few of the lines appear as consistent high or low yielders. Several numbers will be found in both tables, showing that lines have swung from one extreme to the other.

TABLE II.—*Three-year summary of yields of marketable tubers per acre from 108 Green Mountain tuber lines*

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
300	10,453	20,442	26,017	18,970
301	10,453	23,230	16,261	16,648
302	11,034	22,300	19,071	17,468
304	12,776	26,946	14,247	17,989
305	13,357	22,553	15,486	17,132
306	15,680	30,199	29,340	25,073
307	11,615	21,836	14,402	15,951
308	6,969	27,411	11,873	15,417
309	12,776	26,017	11,615	16,802
310	13,938	20,442	26,482	20,287
311	11,615	23,230	21,603	18,816
312	12,195	19,513	13,938	15,215
313	9,872	25,553	13,705	16,376
314	11,034	26,482	10,840	16,118
315	11,615	31,128	16,626	19,789
316	15,608	24,623	11,736	17,322
317	15,099	33,915	23,472	24,162
318	13,938	30,199	10,269	18,135
319	13,938	17,190	21,371	17,499
320	15,099	22,765	30,663	22,842
321	9,292	22,300	15,099	15,563
322	11,615	26,017	16,626	18,086
323	13,938	32,057	13,938	19,977
324	15,680	37,168	21,836	24,894
325	11,615	29,734	19,164	20,171
326	11,034	34,380	20,907	22,107
327	10,453	37,632	14,867	20,984
328	10,453	15,796	10,453	12,234
329	10,453	28,340	13,936	17,576
330	9,292	27,876	30,318	22,495
331	7,549	26,946	23,230	19,241
332	15,099	39,026	29,424	27,849
333	14,518	37,632	25,320	25,823
334	10,453	24,623	10,221	15,099
335	11,615	33,915	16,028	20,519
336	11,034	36,238	14,670	20,647
337	12,195	15,331	7,665	11,730
338	19,164	29,269	22,738	23,723
339	12,195	19,513	10,513	14,073
340	13,357	28,340	24,262	21,986
341	5,807	29,269	8,595	14,557
342	6,969	23,230	11,615	13,938
343	12,195	35,309	26,249	24,584
344	1,742	9,292	489	3,841
345	15,680	14,402	1,366	10,482
346	9,292	10,685	8,001	9,326
347	10,453	17,654	6,968	11,691
348	14,518	18,584	30,715	21,272
349	8,130	23,230	12,776	14,712
350	10,453	24,159	15,796	16,802
351	13,938	27,875	15,099	18,970
352	14,518	28,495	19,048	20,687
353	12,195	26,946	20,674	19,938
354	17,422	33,451	31,128	27,333
355	14,518	22,765	20,293	19,192
356	10,453	19,048	8,362	12,621
357	12,776	18,584	18,351	16,570
358	10,453	23,694	11,751	15,299
359	11,034	27,876	13,936	17,615

TABLE II.—*Three-year summary of yields of marketable tubers per acre from 108 Green Mountain tuber lines*—Continued

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
360	13,936	25,553	20,674	20,054
361	11,615	22,300	26,714	20,202
362	11,615	31,592	29,966	24,399
363	12,195	32,766	30,807	25,251
364	7,549	21,836	9,292	12,896
365	10,453	23,230	11,150	14,944
366	9,292	34,380	14,670	19,447
367	8,130	27,876	19,745	18,583
368	11,034	23,230	9,808	14,690
369	9,292	22,300	13,692	15,094
370	10,453	16,261	7,824	11,512
371	11,034	31,128	17,604	19,922
372	13,357	30,321	31,296	24,991
373	15,099	34,845	24,205	24,716
374	6,388	20,442	5,342	10,724
375	11,613	29,343	11,980	17,645
376	9,872	33,915	30,073	24,620
377	8,516	33,849	22,997	21,787
378	6,969	27,411	19,513	17,964
379	10,453	22,765	15,099	16,105
380	12,195	25,553	13,274	17,007
381	8,130	21,029	7,433	12,197
382	13,938	27,876	19,100	20,304
383	12,195	35,309	22,983	23,495
384	8,711	26,017	16,261	16,996
385	5,807	21,371	4,181	10,453
386	12,776	32,522	13,008	19,435
387	14,518	23,230	12,079	16,609
388	16,261	38,581	27,873	27,571
389	9,872	24,941	12,714	15,842
390	15,099	32,522	28,362	25,327
391	16,259	30,663	32,986	26,636
392	12,776	24,623	12,079	16,492
393	13,357	25,088	13,241	17,228
394	7,549	34,380	20,674	20,867
395	5,807	34,722	12,079	17,536
396	7,549	36,238	25,088	22,958
397	10,065	21,836	19,513	17,138
398	8,130	30,663	28,572	22,455
399	9,872	29,269	22,997	20,712
400	8,130	28,590	29,269	21,996
401	9,292	23,694	11,873	14,953
402	7,549	20,907	6,504	11,653
403	6,388	26,017	13,203	15,202
404	15,099	34,845	22,713	24,219
405	11,615	30,663	15,159	19,145
406	12,776	30,199	22,005	21,660
407	11,613	23,694	18,584	17,963
408	9,291	19,298	11,615	13,401
Yearly average	11,335	26,595	17,493	18,474

TABLE III.—*Twenty highest annual rankings and 3-year average rankings from 108 Green Mountain tuber lines* [a]

1918		1917		1916		3-year average.	
Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
**391	32, 986	332	39, 026	*338	19, 165	***332	27, 849
*372	31, 296	388	38, 582	354	17, 423	***388	27, 571
***354	31, 128	333	37, 633	388	16, 261	***354	27, 333
*363	30, 807	*327	37, 633	391	16, 259	**391	26, 636
**348	30, 715	**324	37, 168	306	15, 680	***333	25, 823
**320	30, 663	*396	36, 239	*316	15, 680	**390	25, 327
*330	30, 318	*336	36, 239	*345	15, 680	*363	25, 256
**376	30, 073	343	35, 310	324	15, 680	**306	25, 073
*362	29, 966	*383	35, 310	317	15, 099	*372	24, 991
***332	29, 424	**404	34, 845	373	15, 099	**324	24, 894
**306	29, 340	**373	34, 845	404	15, 099	**373	24, 716
*400	29, 269	*395	34, 723	332	15, 099	**376	24, 620
*398	28, 572	*394	34, 380	390	15, 099	**343	24, 584
**390	28, 362	*366	34, 380	320	15, 099	*362	24, 391
***388	27, 873	*326	34, 380	333	14, 519	**404	24, 219
*361	26, 714	376	33, 916	*387	14, 519	**317	24, 162
**310	26, 482	*335	33, 916	*355	14, 519	*338	23, 723
**343	26, 249	**317	33, 916	*352	14, 519	*383	23, 495
*300	26, 017	*377	33, 849	348	14, 519	**320	22, 842
***333	25, 320	354	33, 451	310	13, 938	*330	22, 495
				*318	13, 938		
				*319	13, 938		
				*323	13, 938		
				*351	13, 938		
				*382	13, 938		

[a] The number of stars indicates how many times the line has appeared among the 20 highest-yielding lines. Lines not starred in columns 3 and 5 appear and are starred elsewhere in the table. Four lines appear three times, 12 appear twice, and 29 appear only once.

TABLE IV.—*Twenty lowest annual rankings and 3-year average rankings from 108 Green Mountain tuber lines* [a]

1918		1917		1916		3-year average.	
Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
**344	489	344	9, 292	341	5, 808	**314	3, 841
**345	1, 368	346	10, 686	385	5, 808	**346	9, 326
***385	4, 181	345	14, 403	*395	5, 808	***385	10, 453
***374	5, 342	337	15, 332	374	6, 388	**345	10, 482
***402	6, 504	328	15, 796	*403	6, 388	***374	10, 724
**347	6, 968	*330	16, 261	*378	6, 969	*370	11, 512
***381	7, 433	*319	17, 190	*342	6, 969	***402	11, 653
**337	7, 665	347	17, 655	*308	6, 969	**347	11, 691
*370	7, 824	*348	18, 584	402	7, 550	**337	11, 730
**346	8, 001	*357	18, 584	364	7, 550	***381	12, 197
**356	8, 362	356	19, 049	*394	7, 550	**328	12, 234
**341	8, 595	*408	19, 299	*396	7, 550	**356	12, 621
**364	9, 292	339	19, 513	*331	7, 550	**364	12, 892
*368	9, 808	*312	19, 513	*349	8, 131	*408	13, 401
*334	10, 221	*310	20, 442	*367	8, 131	*342	13, 938
*318	10, 269	374	20, 442	*398	8, 131	**339	14, 073
**328	10, 453	*300	20, 442	*400	8, 131	**341	14, 557
**339	10, 513	402	20, 907	381	8, 131	*368	14, 690
*314	10, 840	381	21, 029	*377	8, 517	*349	14, 712
*365	11, 150	385	21, 372	*384	8, 711	*365	14, 944

[a] The number of stars indicates how many years the line has appeared among the 20 lowest-yielding lines. Lines not starred in columns 3 and 5 appear and are starred elsewhere in the table. Four appear three times, 10 appear twice, and 28 appear only once.

If with these records before us we attempt to point out apparently promising lines, we must base our judgment either upon the frequency with which the line appears among the high-yielding lines or upon its performance as indicated by the 3-year average. The following 1918 field notes are upon the lines that have appeared at least two out of the three seasons among the 20 highest or that rank with the 20 highest according to the 3-year average.

LINE NO.	REMARKS.
332.	First two units lacking in vigor but others vigorous. Variations may be due to soil.
388.	Fourth unit a typical semi-curlydwarf.
354.	First unit semi-curlydwarf.
391.	A good vigorous type.
333.	A good vigorous type.
390.	A good vigorous type.
363.	A good vigorous type; third unit inclined to semi-curlydwarf.
306.	First unit curlydwarf; others fairly vigorous.
372.	A good vigorous type.
324.	A fairly good type; a few weak plants, but these may possibly be due to soil.
373.	Variable as to vigor; some plants with curlydwarf tendencies, though all are fairly vigorous.
343.	A good vigorous type with exception of first unit.
362.	A good vigorous type.
404.	A good vigorous type.
317.	A good vigorous type.
338.	A good vigorous type.
383.	A very good type; some variation as to vigor, but this may possibly be due to soil.
320.	Vigorous with exception of third unit, which is a typical semi-curlydwarf.
330.	A good vigorous type.
348.	Units 1, 4, and 5, very vigorous; other two very good type.
310.	First unit with curlydwarf tendencies; others very vigorous.

Of these 22 lines, only 9 were noted as having uniformly good vine characteristics in 1918. Eight contained four or more hills with degenerate tendencies, and 5 showed variations in vigor which possibly might have been attributed to soil but which may, on the other hand, turn out to be the first signs of degeneration. Yield records do not promise to be very effective in dealing with degeneration. It is true that those lines which have appeared frequently among the lowest-yielding are typical degenerates, but degenerate tendencies are also noticeable among the high-yielding ones. On the other hand, 7 of the 19 lines noted with good vine characteristics in 1918 have each appeared once among the low-yielding 20 in Table IV. This indicates that low yields are not always associated with degeneration.

The number of tubers produced in the hill is often suggested as a point worth considering in making seed-potato selections. In Table V will be found a summary of numerical tuber production in the 108 Green Mountain tuber lines. There is a maximum variation in the 3-year averages of 3.45 tubers per single-stemmed hill. The 20 ranking highest in

numerical tuber production (Table VI) have as a group a 3-year average record of 4.04 tubers per hill, while the 20 ranking lowest (Table VII) have averaged for the 3-year period 2.40 tubers per hill. The number of tubers produced in the hills varies from year to year, as will be shown in the yearly averages of the different lines. The 108 Green Mountain lines averaged 1.96 tubers per hill in 1916, 3.97 in 1917, and 2.78 in 1918. Variable soil moisture conditions during the setting period are no doubt responsible for a goodly portion of this fluctuation in tuber production, although delayed thinning may have contributed to the low yields of 1916. In a general way, numerical tuber production and production by weight rise and fall together, but this is by no means a fixed rule. Lines of this variety show the greatest variance in numerical tuber production, but this is no doubt accounted for by the more pronounced degenerate tendencies among a larger proportion of these lines. Degenerate lines do not fall off so much in total number of tubers produced, but a larger proportion of the tubers grade below marketable size. Once degeneration begins in this variety, the line rapidly loses in vitality and yielding power. To illustrate this we might call attention to the record of line 345. This yielded 15,680 pounds per acre in 1916, while the average of all Green Mountain lines for that year was 11,335 pounds. In 1917 it yielded 14,402 pounds as compared with an average of 26,595 for all Green Mountain lines; and in 1918 it yielded 1,366 pounds, as compared with an average of 17,494 for all these lines. Expressed in plus and minus variations, this line yielded 4,345 pounds above the average in 1916, 12,193 below the average in 1917, and 16,127 below the average in 1918.

TABLE V.—*Three-year average numerical production of marketable tubers per hill from 108 Green Mountain tuber lines*

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
300	3.56	328	3.12	355	3.69	382	3.95
301	3.22	329	3.65	356	2.79	383	4.27
302	3.22	330	4.18	357	3.40	384	3.05
304	3.30	331	3.29	358	2.90	385	2.13
305	2.88	332	4.64	359	3.04	386	3.11
306	3.74	333	4.36	360	2.83	387	2.72
307	2.13	334	2.75	361	3.06	388	3.72
308	2.92	335	3.54	362	3.84	389	2.71
309	2.95	336	3.02	363	3.37	390	3.63
310	3.75	337	2.79	364	3.20	391	3.97
311	3.50	338	4.06	365	3.45	392	2.93
312	2.88	339	2.65	366	3.13	393	3.20
313	3.06	340	3.21	367	3.50	394	3.81
314	3.16	341	2.90	368	2.57	395	3.57
315	3.11	342	3.02	369	2.44	396	3.93
316	3.30	343	3.84	370	2.16	397	2.83
317	3.48	344	1.19	371	3.11	398	3.68
318	3.34	345	1.95	372	3.42	399	3.36
319	3.36	346	2.95	373	4.32	400	3.62
320	3.68	347	2.59	374	2.70	401	3.16
321	2.78	348	3.40	375	3.14	402	2.40
322	3.16	349	2.56	376	4.41	403	3.30
323	3.50	350	3.09	377	3.53	404	4.43
324	3.75	351	3.30	378	3.38	405	3.23
325	3.27	352	2.87	379	2.68	406	3.86
326	3.61	353	2.93	380	2.78	407	2.83
327	3.43	354	3.93	381	1.86	408	2.30

TABLE VI.—*Twenty highest-yielding of 108 Green Mountain tuber lines when ranked on 3-year average numerical production of marketable tubers per hill* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
***332**......	**4.64**	***383**......	**4.27**	**396**......	**3.93**	***362**......	**3.84**
***404**......	**4.43**	***330**......	**4.18**	*354......	3.93	**394**......	**3.81**
*376......	4.41	***338**......	**4.06**	*320......	3.88	*324......	3.75
***333**......	**4.36**	***391**......	**3.97**	406......	3.86	310......	3.75
*373......	4.32	382......	3.95	*343......	3.84	*306......	3.74

[a] The 15 starred lines also appear among the 20 highest-yielding when ranked on the 3-year average production of marketable tubers by weight. Ten of these lines, printed in bold-face type, appear among the 19 lines selected in 1918 as having uniformly good vine characteristics. Average of group, 4.40 tubers per hill.

TABLE VII.—*Twenty lowest-yielding of 108 Green Mountain tuber lines when ranked on 3-year average numerical production of marketable tubers per hill* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
*344......	1.19	*370......	2.16	*368......	2.57	389......	2.71
*381......	1.86	*408......	2.30	*347......	2.59	387......	2.72
*345......	1.95	*402......	2.40	*339......	2.65	334......	2.75
*385......	2.13	369......	2.44	379......	2.68	321......	2.78
307......	2.13	*349......	2.56	*374......	2.70	380......	2.78

[a] The 12 lines starred also appear among the 20 ranking lowest in weight of marketable tubers. None of these 20 low-yielding lines have good vine characteristics. Average of group, 2.40 tubers per hill.

The 19 lines selected in 1918 as having uniformly good vine characteristics have been grouped in Table VIII. The 1918 average of these 19 lines is 26,260 pounds. In Table IX appear an equal number of the heaviest-yielding lines of 1918, with an average production for the year of 29,267 pounds. The 108 Green Mountain lines gave an average yield of 17,493 pounds in 1918. It will be noted that selection based upon vine characteristics alone came very near isolating the high-yielding lines for that season. The 19 lines appearing in Table VIII have as a group a 3-year average record of 23,270 pounds of marketable tubers per acre. The 19 lines standing highest when ranked on their 3-year average yield of marketable tubers have as a group an average of 25,131 pounds. The variation between the two groups, 1,861 pounds per acre, hardly seems sufficient to repay the labor involved in keeping yield records.

TABLE VIII.—*Yields of 19 Green Mountain lines chosen upon vine characteristics alone as the best of the 108 lines of this variety in 1918* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
300......	26,071	*338......	22,738	*372......	31,296	394......	20,674
*317......	23,472	340......	24,262	377......	22,997	396......	25,088
*330......	30,318	348......	30,715	*383......	22,983	400......	29,269
*332......	29,424	355......	20,293	*390......	28,362	*404......	22,713
*333......	25,320	*362......	29,966	*391......	32,989		

[a] The lines starred appear among the 20 highest-yielding lines when ranked on the 3-year average production by weight of marketable tubers. Average of group, 26,260 pounds per acre.

TABLE IX.—*Nineteen highest-yielding of 108 Green Mountain lines in 1918* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
391	**32,986**	320	30,663	306	29,340	361	26,714
372	**31,296**	**330**	**30,318**	**400**	**29,269**	310	26,482
354	31,128	376	30,073	398	28,572	343	26,249
363	30,807	**362**	**29,966**	**390**	**28,362**	**300**	**26,017**
348	**30,715**	**332**	**29,424**	388	27,873		

[a] The lines printed in bold-face type also appear in the group with good vine characteristics. This leaves 10 of the 19 lines with vines suggesting degenerate tendencies. Average of group, 29,267 pounds per acre.

RURAL NEW YORKER TUBER LINES 409 TO 516

Rural New Yorker has ranked very high in the variety tests conducted at this Station. Experience would lead to the belief that, with the possible exception of Russet Burbank, no main crop variety tested in these experiments will give more uniformly satisfactory results upon heavy types of irrigated land. Usually little difficulty is experienced in maintaining good, vigorous stock where the seed is carefully selected after the digger. The average yield of all strains of Rural tested in 1916, 1917, and 1918 was 13,449 pounds of marketable tubers per acre. It will be noted that the average yield of the 108 tuber lines for the same period was 16,820 pounds. The 3-year performance record of these lines is presented in Table X. Here, as well as in Table II, it is interesting to note the variation in the average annual yield of all lines for the three seasons. Within any one season the variation between tuber lines is not so pronounced as it is in Green Mountain; but as yet none of these lines has reached the final stage of degeneration as several Green Mountain lines have. No effort is made to draw conclusions from Table X as a whole, but in Tables XI and XII an effort has been made to present a portion of the data included in Table X in such form that we may get some idea of the value of a 3-year performance record in isolating high-yielding lines.

TABLE X.—*Three-year summary of yields of marketable tubers per acre from 108 Rural New Yorker tuber lines*

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
409	12,776	22,007	17,422	17,401
410	9,872	20,907	18,351	16,376
411	9,292	22,300	22,956	18,182
412	13,357	26,327	24,939	21,541
413	9,292	27,876	15,648	17,605
414	9,872	23,230	26,585	19,895
415	12,776	25,919	23,961	20,885
416	12,776	21,371	28,108	20,751
417	8,130	24,623	22,683	18,478
418	4,065	17,869	14,867	12,267
419	11,034	24,159	20,442	18,545
420	7,549	24,159	20,442	17,383
421	8,711	25,088	18,584	17,461

TABLE X.—*Three-year summary of yields of marketable tubers per acre from 108 Rural New Yorker tuber lines*—Continued

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
422	11,615	28,340	17,190	19,048
423	12,776	23,230	14,867	16,957
424	11,615	27,386	24,049	21,017
425	8,711	21,836	28,362	19,636
426	8,711	24,159	21,165	18,011
427	10,453	21,836	17,654	16,647
428	1,742	34,070	18,351	18,054
429	7,742	22,765	16,626	15,711
430	6,388	23,230	26,650	18,756
431	6,388	26,946	17,551	16,961
432	9,291	25,430	15,159	16,626
433	9,872	26,482	24,623	20,325
434	6,969	27,031	26,714	20,238
435	7,549	23,230	21,516	17,431
436	6,969	23,230	22,765	17,654
437	8,130	25,088	18,119	17,112
438	6,388	21,836	18,582	15,602
439	6,388	20,442	25,428	17,419
440	9,292	23,230	21,371	17,964
441	6,969	22,300	20,132	16,467
442	6,388	24,623	27,873	19,628
443	10,453	25,088	27,876	21,139
444	10,453	19,048	17,035	15,512
445	11,615	19,513	19,977	17,035
446	11,613	26,482	19,745	19,280
447	9,292	16,002	21,589	15,627
448	13,938	24,452	23,229	20,539
449	12,776	23,694	17,422	17,964
450	12,195	23,230	25,142	20,189
451	11,034	25,430	25,428	20,630
452	11,034	26,017	20,648	19,233
453	6,388	26,017	13,938	15,447
454	5,807	14,402	18,093	12,767
455	10,453	22,765	19,048	17,422
456	11,615	13,938	17,035	14,196
457	12,195	23,230	10,758	15,394
458	9,292	22,300	19,071	16,887
459	9,292	22,765	17,654	16,570
460	11,034	20,442	20,049	17,175
461	9,292	20,907	13,473	14,557
462	10,453	24,159	19,071	17,894
463	11,034	16,261	16,519	14,604
464	8,711	23,230	17,035	16,325
465	8,130	19,048	24,939	17,372
466	8,130	21,836	18,093	16,019
467	7,549	23,694	18,093	16,445
468	5,807	19,676	13,692	13,058
469	9,872	19,513	20,907	16,764
470	5,807	22,300	20,538	16,215
471	5,226	19,977	18,582	14,595
472	7,549	16,261	18,351	14,053
473	5,807	18,119	17,359	13,761
474	7,549	19,977	17,422	14,982
475	6,969	20,442	17,035	14,815
476	8,130	23,694	20,442	17,422
477	5,807	19,513	12,544	12,621
478	8,130	22,300	18,067	16,165
479	8,711	19,513	18,857	15,693
480	10,453	23,230	22,400	18,697

TABLE X.—*Three-year summary of yields of marketable tubers per acre from 108 Rural New Yorker tuber lines*—Continued

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
481	10, 453	16, 725	17, 035	14, 737
482	11, 615	18, 584	20, 538	16, 912
483	9, 292	16, 261	11, 247	12, 266
484	8, 711	12, 195	17, 551	12, 819
485	11, 615	20, 907	18, 119	16, 880
486	10, 453	17, 654	24, 049	17, 385
487	9, 292	18, 119	21, 371	16, 260
488	5, 807	19, 048	19, 048	14, 634
489	6, 969	18, 584	22, 494	16, 015
490	10, 453	18, 584	13, 692	14, 243
491	11, 613	22, 300	17, 887	17, 266
492	8, 711	23, 694	23, 488	18, 631
493	11, 615	18, 584	18, 826	16, 341
494	9, 872	20, 442	16, 260	15, 524
495	12, 195	19, 048	19, 315	16, 852
496	13, 938	19, 513	21, 760	18, 403
497	10, 453	23, 694	20, 674	18, 273
498	8, 130	19, 513	22, 455	16, 699
499	8, 130	21, 029	17, 190	15, 449
500	4, 646	22, 300	14, 670	13, 872
501	4, 646	22, 765	22, 765	16, 725
502	6, 969	22, 765	19, 977	16, 570
503	6, 388	20, 907	19, 513	15, 602
504	4, 646	23, 230	20, 442	16, 106
505	9, 872	18, 584	18, 093	15, 516
506	4, 646	24, 623	20, 049	16, 439
507	5, 226	19, 048	21, 516	15, 263
508	7, 549	21, 371	17, 115	15, 345
509	8, 711	21, 029	12, 389	14, 043
510	4, 646	25, 088	25, 552	18, 428
511	8, 711	21, 836	19, 560	16, 702
512	6, 969	22, 300	19, 560	16, 276
513	6, 969	22, 300	20, 674	16, 647
514	6, 969	22, 300	20, 442	16, 570
515	9, 292	22, 300	17, 654	16, 415
516	8, 130	17, 190	20, 907	15, 409
Average	8, 831	21, 864	19, 787	16, 820

The data included in these tables indicate that with few exceptions high-yielding lines are not consistent high yielders, neither are all low-yielding lines consistent low yielders. The following brief field notes taken in 1918 do not indicate that yield records will be found very satisfactory in dealing with degeneration. For instance, line 448 has a very good performance record. It ranked first in 1916, appeared among the highest-yielding 20 in 1918, only missed by a narrow margin a place among the best 20 in 1917, and ranks seventh according to the 3-year average. But unless the vine characteristics are very deceiving, its yielding power will drop at least 50 per cent during the next two years. One-third of these lines with promising performance records contained some plants with degenerate tendencies. The field notes of 1918 indicate to what extent degeneration appears among the lines that have appeared for at least two out of three years among the 20 highest-yielding or would be ranked with the 20 highest according to the 3-year average.

TABLE XI.—*Twenty highest annual rankings and 3-year average rankings from 108 Rural New Yorker tuber lines* [a]

1918		1917		1916		3-year average.	
Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
*425	28,362	*428	34,070	448	13,938	***412	21,541
**416	28,108	**422	28,341	*496	13,938	**443	21,139
**443	27,876	*413	27,876	412	13,357	***424	21,017
**442	27,873	424	27,387	415	12,777	***415	20,885
**434	26,714	434	27,031	*449	12,777	**416	20,751
*430	26,650	*431	26,947	*423	12,777	**451	20,630
*414	26,585	433	26,482	416	12,777	**448	20,539
**510	25,552	**446	26,482	*409	12,777	**433	20,325
**451	25,428	412	26,327	*495	12,196	**434	20,238
*439	25,438	*453	26,081	*457	12,196	**450	20,189
**450	25,142	*452	26,081	450	12,196	*414	19,895
*465	24,939	415	25,920	424	11,615	*425	19,636
***412	24,939	451	25,430	422	11,615	**442	19,628
**433	24,623	*432	25,430	*493	11,615	**446	19,280
***424	24,049	510	25,088	*485	11,615	*452	19,233
*486	24,049	443	25,088	*482	11,615	**422	19,048
***415	23,961	*437	25,088	*456	11,615	*430	18,756
*492	23,488	*421	25,088	*455	11,615	480	18,697
**448	23,229	442	24,624	446	11,614	*492	18,631
*411	22,956	*506	24,624	*491	11,614	419	18,545
		*417	24,624				

[a] The number of stars indicates how many times the line has appeared among the 20 highest rankings. Lines not starred in columns 3 and 5 appear and are starred elsewhere in the table. Three lines appear three times, 11 lines appear twice, and 30 lines appear only once.

TABLE XII.—*Twenty lowest annual rankings and 3-year average rankings from 108 Rural New Yorker tuber lines* [a]

1918		1917		1916		3-year average.	
Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
*457	10,758	*484	12,196	*428	1,742	**483	12,266
**483	11,247	456	13,938	418	4,065	***418	12,267
*509	12,389	*454	14,403	*506	4,646	**477	12,621
**477	12,544	*447	16,003	*510	4,646	*454	12,767
*461	13,473	*472	16,261	*504	4,646	*484	12,819
**468	13,692	463	16,261	*501	4,646	**468	13,058
**490	13,692	483	16,261	500	4,646	**473	13,761
**453	13,938	481	16,726	507	5,227	**500	13,872
**500	14,670	*516	17,190	*471	5,227	*509	14,043
***418	14,867	*486	17,665	473	5,808	*472	14,053
*423	14,867	418	17,869	*450	5,808	**456	14,196
*432	15,159	**473	18,119	468	5,808	**490	14,243
*413	15,648	*487	18,119	477	5,808	*461	14,557
*494	16,260	*489	18,584	488	5,808	*471	14,595
**463	16,519	490	18,584	*470	5,808	**463	14,604
*429	16,626	*505	18,584	*442	6,388	**488	14,634
**481	17,035	*482	18,584	453	6,388	**481	14,737
*464	17,035	*493	18,584	*431	6,388	*475	14,815
*475	17,035	*495	19,049	*503	6,388	474	14,982
**456	17,035	**488	19,049	*439	6,388	**507	15,262
**444	17,035	444	19,049	*430	6,388		
		*465	19,049	*438	6,388		
		**507	19,049				

[a] The number of stars indicates how many times the line has appeared among the 20 lowest rankings. Lines not starred in columns 3 and 5 appear and are starred elsewhere in the table. One appears three times, 13 lines appear twice, and 37 lines appear only once.

Of these 21 lines, 7 have curlydwarf tendencies. Twelve appear among the best 33 lines chosen in 1918 on vine characteristics alone. This leaves two, 443 and 452, in the doubtful list.

LINE NO.	REMARKS.
416.	Third unit a curlydwarf; others vigorous though lacking in uniformity.
443.	A very good type; first and second unit not especially vigorous.
442.	A good vigorous type.
434.	A good vigorous type.
510.	A good vigorous type.
451.	A good vigorous type.
450.	Not a very good type.
412.	Uniform and fairly vigorous.
433.	A good vigorous type.
424.	Vines not a good type.
415.	A good type and fairly vigorous.
448.	All have more or less curlydwarf tendency.
422.	Lacking in vigor but type good.
446.	First four units have curlydwarf tendencies.
414.	First unit with curlydwarf tendencies.
425.	Very good and vigorous type.
452.	Not very vigorous but type good.
430.	First unit very vigorous; others good.
480.	Fairly vigorous.
492.	A very good type.
419.	Some curlydwarf tendencies.

In Table XIII data are presented showing the 3-year average numerical production of tubers per single-stemmed hill. In Tables XIV and XV a portion of this data is used to show the lack of correlation between yields in numbers and in weight, as well as the relation between numerical tuber production and good vine characteristics. There is in Table XIII a maximum variation of 1.29 tubers per hill. Between the average of the 20 highest and 20 lowest (Tables XIV and XV) there is a variation of 0.79 tubers per hill. Considering that these are single-stemmed hills, this variation is rather pronounced. But the data are apparently no more reliable than weight records in pointing out promising lines. Low numerical tuber production does not always mean low production by weight, and such records are apparently of little value as a check on degenerate tendencies. Fluctuation in tuber production in different seasons has been even greater than the variation between lines in any one season. These 108 lines averaged 2.05 marketable tubers per hill in 1916, 3.78 in 1917, and 2.44 in 1918.

In Table XVI the 33 lines with promising vine characteristics have been assembled with their 1918 yields of marketable tubers. The average yield of these 33 lines is 21,142 pounds per acre. In Table XVII the 33 heaviest-yielding lines of 1918 are assembled for comparison. Their average yield is 24,109 pounds, while the 1918 average of the 108 Rural New Yorker lines was 19,787 pounds per acre. The lines chosen upon vine

characteristics alone yielded well above the average of the 108 lines but did not equal the 33 heaviest-yielding lines of 1918. Field notes show that 15 of these heavy-yielding lines of 1918 have poor vine characteristics. This means that if mass selection based on tuber characteristics is practiced within these 15 lines their progeny will be almost certain to contain some rather advanced degenerate types that will materially decrease the yield of the lines in 1919. On the other hand, we can be almost sure that no well-advanced or low-yielding degenerates will appear among the 1919 progeny of those with good 1918 vine characteristics. It is interesting to go back beyond the 1918 records and compare the 3-year performance of these lines assembled in Table XVI with the 33 highest-yielding Rural New Yorker lines when ranked upon their 3-year average production. The 33 lines in Table XVI have produced during the 3-year period an average yield of 17,740 pounds per acre. The 33 of the 108 Rural New Yorker lines ranking highest according to the 3-year average production by weight have yielded on an average 19,181 pounds. Between the two groups there is a variation of 1,441 pounds in favor of the 33 lines ranked upon their performance record. But when vine development so nearly foretells the yielding power of the line it would really seem that this is a more practical basis for selection than yields measured in either weight or number of tubers.

TABLE XIII.—*Three-year average numerical production of marketable tubers per hill from 108 rural New Yorker tuber lines*

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
409	3.30	436	3.29	463	3.00	490	2.76
410	3.47	437	3.02	464	3.07	491	2.79
411	3.65	438	3.18	465	3.02	492	3.16
412	3.34	439	3.00	466	2.90	493	2.83
413	3.25	440	2.95	467	3.04	494	2.69
414	2.80	441	3.19	468	2.60	495	2.93
415	3.19	442	3.48	469	3.10	496	2.83
416	3.31	443	2.68	470	3.04	497	3.25
417	2.97	444	3.04	471	2.65	498	2.78
418	2.86	445	3.09	472	3.06	499	2.79
419	3.63	446	3.32	473	3.11	500	2.83
420	3.54	447	3.10	474	3.06	501	3.29
421	3.34	448	3.07	475	3.02	502	3.06
422	3.56	449	2.88	476	2.77	503	2.72
423	2.97	450	3.04	477	2.95	504	2.93
424	3.15	451	3.21	478	3.16	505	2.64
425	3.53	452	3.38	479	3.21	506	3.60
426	3.59	453	3.20	480	3.04	507	3.27
427	3.00	454	2.93	481	3.02	508	2.74
428	2.55	455	2.81	482	2.95	509	2.60
429	3.20	456	2.78	483	2.55	510	3.19
430	3.41	457	2.86	484	2.92	511	3.11
431	3.28	458	3.04	485	2.95	512	3.09
432	3.48	459	3.29	486	3.19	513	3.43
433	3.43	460	3.16	487	2.88	514	2.75
434	3.74	461	2.70	488	2.93	515	2.79
435	3.25	462	2.90	489	3.02	516	2.45

TABLE XIV.—*Twenty highest-yielding of 108 Rural New Yorker tuber lines when ranked on 3-year average numerical production of marketable tubers per hill*[a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
***434**......	**3.74**	***422**......	**3.56**	410......	3.47	***412**......	**3.34**
411......	3.65	420......	3.54	***433**......	**3.43**	421......	3.34
*419......	3.63	***425**......	**3.53**	**513**......	**3.43**	*446......	3.32
506......	**3.60**	432......	3.48	***430**......	**3.41**	*416......	3.31
426......	3.59	***442**......	**3.48**	*452......	3.38	409......	3.30

[a] The 11 lines starred appear among the 20 highest when ranked on 3-year average production by weight of marketable tubers. Nine of these lines (printed in bold-face type) have uniformly good vine characteristics, and the other 11 have vine characteristics which suggest degeneration. Average of group, 3.47 tubers per hill.

TABLE XV.—*Twenty lowest-yielding of 108 Rural New Yorker tuber lines when ranked on 3-year average numerical production of marketable tubers per hill*[a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
516......	**2.45**	505......	2.64	**503**......	**2.72**	*456......	2.78
*483......	2.55	*471......	2.65	**508**......	**2.74**	**498**......	**2.78**
428......	**2.55**	443......	2.68	**514**......	**2.75**	491......	2.79
*509......	2.60	494......	2.69	*490......	2.76	499......	2.79
*468......	2.60	*461......	2.70	476......	2.77	515......	2.79

[a] The 7 lines starred appear among the 20 lowest when ranked on 3-year average production by weight of marketable tubers. The 6 lines printed in bold-face type appeared among the 33 chosen in 1918 as having the best vine characteristics, and these 6 have very good 3-year averages for tuber production by a weight. Line 428 appeared among the heaviest-yielding 20 in 1918 and only missed by a small margin a place among the 20 heaviest-yielding when ranked on 3-year average production. Average of group, 2.68 tubers per hill.

TABLE XVI.—*Yields for 1918 of 33 Rural New Yorker lines chosen upon 1918 vine characteristics alone as the best of the 108 lines of this variety*[a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
*412.......	24,939	*442......	27,873	*492......	23,488	504......	20,442
*413.......	15,648	*451......	25,428	493......	18,826	506......	20,049
*415.......	23,961	465......	24,939	495......	19,315	507......	21,516
*422.......	17,190	*480......	22,409	*496......	21,760	508......	17,115
*425.......	28,362	486......	24,049	*497......	20,674	*510......	25,552
*428.......	18,351	488......	19,048	498......	22,455	513......	20,674
*430.......	26,650	489......	22,494	501......	22,765	514......	20,442
*433.......	24,623	491......	17,887	503......	19,513	516......	20,907
*434.......	26,714						

[a] The 16 lines starred appear among the 33 highest-yielding lines when ranked on their 3-year average record. Lines 488 and 507 rank among the 20 lowest-yielding according to the 3-year average. Average of group, 21,142 pounds per acre.

TABLE XVII.—*Thirty-three highest-yielding lines of 108 Rural New Yorker tuber lines in 1918*[a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
425........	**28,362**	**451**.......	**25,428**	**492**.......	**23,488**	**480**.......	**22,409**
416........	28,108	450.......	25,142	448.......	23,229	**496**.......	**21,760**
443........	27,876	**412**.......	**24,939**	411.......	22,956	447.......	21,589
442........	**27,873**	**465**.......	**24,939**	436.......	22,765	435.......	21,516
434........	**26,714**	**433**.......	**24,623**	**501**.......	**22,765**	**507**.......	**21,516**
430........	**26,650**	424.......	24,049	417.......	22,683	440.......	21,371
414........	26,585	**486**.......	24,049	**489**.......	**22,494**	487.......	21,371
510........	**25,552**	**415**.......	23,961	**498**.......	**22,455**	426.......	21,156
439........	25,428						

[a] The 18 lines printed in bold-face type appear in Table XVI. This means that of the 33 highest-yielding Rural New Yorker lines in 1918, 15 have poor vine characteristics. Average of group, 24,109 pounds per acre.

EARLY SIX WEEKS TUBER LINES 517 TO 622

While these lines were selected from stock being grown under the name of Early Six Weeks, they all seem more typical of Red Early Ohio. At first a mixture of Early Ohio and Early Six Weeks was suspected, but observations on vine characteristics have led to the belief that the less vigorous lines, more typical of Early Six Weeks, are nothing more than degenerate types of Early Ohio. Such types are constantly appearing within vigorous dark green lines typical of Early Ohio. With this explanation I will still refer to these as Early Six Weeks lines. Varieties of the Early Ohio types have proved very satisfactory under soil and climatic conditions at the Station, yielding much better than other standard early varieties like Irish Cobbler and Early Triumph, and with less tendency to degeneration.

The 3-year performance record of these 100 lines is presented in Table XVIII. The average annual yield has followed about the same curve as in the other two varieties. There has apparently been ample variation between lines in any one season and in the 3-year average to furnish a basis for selection. As in the other varieties, however, these variations in yield have in many cases been rather inconsistent.

TABLE XVIII.—*Three-year summary of yields of marketable tubers per acre from 100 Early Six Weeks tuber lines*

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
517	15, 099	20, 907	19, 513	18, 506
518	16, 261	21, 681	8, 802	15, 581
519	10, 453	24, 159	17, 654	17, 422
520	9, 872	24, 004	11, 247	15, 041
522	12, 195	28, 340	19, 804	20, 113
523	12, 195	20, 907	13, 692	15, 598
524	13, 357	21, 371	13, 008	15, 912
525	14, 518	16, 958	21, 271	17, 582
526	12, 776	23, 230	20, 293	18, 766
527	13, 357	19, 977	11, 150	14, 828
528	11, 615	22, 300	12, 469	15, 461
529	13, 938	26, 482	18, 351	19, 590
530	15, 099	22, 765	15, 099	17, 654
531	12, 776	27, 565	22, 713	21, 018
532	16, 261	22, 997	18, 584	19, 280
533	16, 261	25, 320	21, 271	20, 950
534	11, 615	14, 402	15, 099	13, 705
535	6, 969	22, 765	16, 725	15, 486
536	8, 711	25, 088	18, 119	17, 306
537	11, 615	22, 300	15, 331	16, 415
538	9, 292	19, 977	11, 615	13, 628
539	7, 549	21, 836	19, 048	16, 144
540	8, 711	24, 159	19, 977	17, 615
541	11, 615	22, 765	21, 603	18, 661
542	9, 292	20, 648	18, 119	16, 019
543	12, 776	18, 351	22, 300	17, 809
545	6, 969	17, 654	7, 652	10, 758
546	9, 872	25, 088	22, 765	19, 308
547	9, 292	24, 624	13, 473	15, 796
548	11, 034	26, 017	25, 320	20, 790

TABLE XVIII.—*Three-year summary of yields of marketable tubers per acre from 100 Early Six Weeks tuber lines*—Continued

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
549	13, 938	25, 553	24, 391	21, 294
550	12, 195	21, 528	19, 745	17, 822
551	19, 745	24, 623	25, 553	23, 307
552	17, 422	25, 088	25, 553	22, 687
553	10, 453	14, 228	14, 181	12, 954
554	9, 872	25, 553	20, 907	18, 777
555	9, 292	19, 745	13, 936	14, 324
556	13, 357	20, 540	15, 099	16, 332
558	12, 195	26, 186	20, 049	19, 476
559	8, 711	17, 654	17, 887	14, 750
560	12, 776	17, 422	20, 538	16, 912
561	9, 292	20, 442	29, 502	19, 745
562	12, 776	19, 978	27, 873	20, 209
563	15, 099	13, 473	12, 958	13, 843
564	11, 034	23, 694	19, 048	17, 925
565	15, 680	23, 229	20, 907	19, 938
566	11, 034	19, 745	13, 203	14, 660
568	11, 615	37, 942	14, 634	21, 397
569	15, 680	16, 725	20, 210	17, 538
570	12, 195	18, 584	15, 648	15, 475
571	10, 453	18, 816	21, 139	16, 802
572	12, 776	22, 300	18, 351	17, 809
573	9, 292	15, 331	15, 564	13, 395
574	8, 130	21, 836	16, 028	15, 331
575	10, 453	21, 139	19, 977	17, 189
576	10, 453	17, 190	14, 402	14, 015
577	17, 422	26, 017	19, 513	20, 984
578	15, 099	20, 907	13, 241	16, 415
579	14, 518	21, 371	14, 181	16, 690
580	15, 099	23, 694	21, 271	20, 021
581	13, 938	22, 300	16, 397	17, 545
582	12, 776	24, 452	13, 241	16, 823
583	14, 518	25, 553	10, 918	16, 996
584	14, 518	33, 683	19, 071	22, 424
585	9, 292	32, 986	19, 048	20, 442
586	12, 195	26, 017	20, 210	19, 474
588	12, 195	28, 908	14, 425	18, 509
589	15, 099	31, 360	20, 132	22, 197
590	10, 453	23, 230	16, 028	16, 570
591	12, 776	24, 159	20, 907	19, 280
592	13, 938	24, 623	9, 524	16, 028
593	14, 518	28, 968	13, 938	19, 141
594	15, 099	26, 548	17, 654	19, 767
595	12, 195	30, 663	21, 027	21, 295
596	14, 518	30, 199	17, 359	20, 692
597	11, 615	28, 340	13, 473	17, 809
599	11, 615	25, 088	10, 685	15, 796
600	10, 453	26, 017	17, 654	18, 041
601	7, 549	27, 876	19, 048	18, 157
602	11, 615	25, 533	10, 513	15, 887
603	15, 099	28, 853	16, 870	20, 274
604	12, 195	30, 810	21, 516	21, 507
605	14, 518	29, 343	20, 442	21, 434
606	13, 357	28, 340	15, 403	19, 033
607	13, 938	29, 966	18, 584	20, 829
608	11, 615	30, 199	22, 005	21, 273
609	9, 292	29, 734	21, 516	20, 180
610	11, 615	27, 876	16, 261	18, 584
611	13, 938	24, 623	11, 615	16, 725

TABLE XVIII.—*Three-year summary of yields of marketable tubers per acre from 100 Early Six Weeks tuber lines*—Continued

Tuber line No.	1916	1917	1918	3-year average.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
612	15,099	29,734	15,331	20,054
613	12,195	25,088	16,137	17,806
614	15,099	29,269	18,584	20,984
615	11,034	25,088	13,473	16,531
616	13,938	25,919	12,544	17,467
617	13,938	27,876	18,582	20,132
618	15,099	30,663	19,048	21,603
619	9,292	25,088	15,564	16,648
620	11,034	21,518	18,119	16,890
621	8,711	16,725	4,646	10,027
622	12,195	26,485	19,358	19,345
Average	12,334	24,048	17,344	17,909

TABLE XIX.—*Twenty highest annual rankings and 3-year average rankings from 100 Early Six Weeks tuber lines* [a]

1918		1917		1916		3-year average.	
Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
*561	29,502	*568	37,942	551	19,746	**551	23,307
*562	27,873	**584	33,684	552	17,423	**552	22,687
**552	25,553	*585	32,987	*577	17,423	**584	22,424
**551	25,553	**589	31,361	*518	16,261	**589	22,197
*548	25,320	604	30,810	*532	16,261	**618	21,603
*549	24,391	*595	30,663	533	16,261	**604	21,507
*546	22,765	**618	30,663	565	15,680	**605	21,434
*531	22,713	608	30,119	*569	15,680	*568	21,397
*543	22,300	**596	30,119	*578	15,099	*595	21,295
**608	22,005	*607	29,966	580	15,099	*549	21,294
*541	21,603	609	29,734	*594	15,099	**608	21,273
**609	21,516	**612	29,734	589	15,099	*531	21,018
**604	21,516	**605	29,343	618	15,099	**614	20,984
**580	21,271	**614	29,269	612	15,099	*577	20,984
**525	21,271	**593	28,969	614	15,099	**533	20,950
**533	21,271	*588	28,908	603	15,099	*607	20,829
*571	21,139	**603	28,854	*563	15,099	*548	20,790
*595	21,027	*606	28,341	*530	15,099	**696	20,692
*591	20,907	*597	28,340	*517	15,099	*585	20,442
**565	20,907	*522	28,340	*583	14,518	**603	20,274
*554	20,907			525	14,518		
				*579	14,518		
				584	14,518		
				593	14,518		
				596	14,518		
				605	14,518		

[a] The number of stars indicates how many times the line has appeared among the 20 highest rankings. Lines not starred in columns 3 and 5 appear and are starred elsewhere in the table. None appear three times, 18 appear twice, and 31 appear only once.

In Tables XIX and XX a portion of the data from Table XVIII is assembled for the purpose of a more critical study of the performance of the highest-yielding and lowest-yielding 20 of the 100 lines.

TABLE XX.—*Twenty lowest annual rankings and 3-year average rankings from 108 Early Six Weeks tuber lines* [a]

1918		1917		1916		3-year average.	
Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
***621	4, 646	563	13, 473	*535	6, 969	***621	10, 027
***545	7, 652	*553	14, 228	545	6, 969	***545	10, 758
*518	8, 802	*534	14, 402	*601	7, 550	*553	12, 954
*592	9, 524	**573	15, 332	*539	7, 550	**573	13, 395
*602	10, 513	*569	16, 725	*574	8, 131	***538	13, 628
*599	10, 685	621	16, 726	*536	8, 711	*534	13, 705
*583	10, 918	*525	16, 958	*540	8, 711	**563	13, 843
*527	11, 150	*576	17, 190	621	8, 711	*576	14, 015
**520	11, 247	*560	17, 422	559	8, 711	**555	14, 324
*611	11, 615	**559	17, 654	538	9, 292	**566	14, 660
***538	11, 615	545	17, 654	555	9, 292	**559	14, 750
*528	12, 469	*543	18, 351	573	9, 292	*527	14, 828
*616	12, 544	*570	18, 584	561	9, 292	**520	15, 041
**563	12, 958	*571	18, 816	*542	9, 292	*574	15, 331
*524	13, 008	**555	19, 745	*609	9, 292	*528	15, 461
**566	13, 203	566	19, 746	*585	9, 292	*570	15, 475
*578	13, 241	*527	19, 977	*619	9, 292	*535	15, 486
*582	13, 241	538	19, 977	547	9, 292	*518	15, 581
**547	13, 473	*562	19, 978	*546	9, 872	523	15, 598
*597	13, 473	**561	20, 442	*554	9, 872	**547	15, 796
*615	13, 473			*505	9, 872	*599	15, 796
				520	9, 872		

[a] The number of stars indicates how many times the line has ranked among the lowest 20. Lines not starred in columns 3 and 5 appear and are starred elsewhere in the table. Three appear three times, 8 appear twice, and 38 appear only once.

It will be noted from Tables XIX and XX that in either case the greater number of these lines have appeared only once in either of these groups. Line 561 appears in the low-yielding groups of 1916 and 1917 but is the highest-yielding line of 1918. It also appears among the 40 lines selected in 1918 as having the best vines. While the performance record may not so indicate, it is undoubtedly one of the good lines of this variety. Aside from this one line, none of those that have ranked twice among the lowest 20 according to the 3-year average appear among those selected in 1918 as having good vine characteristics. We may safely say that the performance record is more reliable as a means of eliminating the lowest-yielding lines than in pointing out the higher-yielding ones. The following 1918 field notes show that in this as well as in the other varieties yield records will not eliminate lines with degenerate tendencies.

LINE NO.	REMARKS.
552.	A good dark green type.
551.	A good dark green type.
608.	A good dark green type.
609.	A good dark green type.
604.	A good dark green type.
580.	A good dark green type.
525.	Third unit lacking in color; others good.
584.	A good dark green type.
589.	First unit not a good type.
618.	A good dark green type.
596.	A good dark green type.
612.	First unit lacking in color.
605.	A good dark green type.
614.	Third, fourth, and fifth units not good type.
593.	Color not good although the line is quite vigorous.
603.	A good dark green type.
568.	Lacking in color but fairly vigorous.
595.	A good dark green type.
549.	A good dark green type.
531.	Last unit showing a tendency to burn.
577.	A good dark green type.
607.	A good dark green type.
548.	A good dark green type.
585.	Last unit light-colored and burning; others very good.

Of these 26 lines which have appeared at least twice among the highest-ranking 20 or would be ranked among the highest 20 on their 3-year average production by weight, 17 have good records as to vine characteristics and 9 contain some vines of a degenerate type. It will be remembered that loss of vitality is indicated in this variety by a loss of color and a tendency for the leaves to burn about the edges in typical degenerates.

In Table XXI will be found data upon the 3-year average numerical tuber production of Early Six Weeks. The maximum variation found is 1.78 tubers per hill. The annual average tuber production shows even greater variation. These 100 tuber lines averaged 2.12 tubers per hill in 1916, 4.04 in 1917, and 2.63 in 1918. The 20 highest and 20 lowest yielding lines when ranked upon tuber production in numbers have been grouped in Tables XXII and XXIII. The first 8 lines starred in Table XXIII are typical degenerates with bad yield records by weight. There are, however, 5 lines in Table XXIII which also appear in Table XXIV among the 40 with good vine characteristics in 1918. Going back to Table XVIII, it will be noticed that these 5 lines have very good records when judged on tuber production by weight. It is true that none of them are high yielders, but they fall very close to the average of the 100 lines. Fourteen of the lines in Table XXII appear in Table XXIV, or among those selected in 1918 as having good vine characteristics.

TABLE XXI.—*Three-year average numerical production of marketable tubers per hill from 100 Early Six Weeks tuber lines*

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
517	3.02	543	2.77	571	3.18	597	3.25
518	2.41	545	2.41	572	3.20	599	3.22
519	2.84	546	3.29	573	2.70	600	3.15
520	2.69	547	3.25	574	3.15	601	3.29
522	3.00	548	3.65	575	3.27	602	3.27
523	3.07	549	3.63	576	2.84	603	3.47
524	2.86	550	2.92	577	3.95	604	3.85
525	3.23	551	3.50	578	3.00	605	3.25
526	2.90	552	3.11	579	2.86	606	3.32
527	2.79	553	3.17	580	3.23	607	3.50
528	3.16	554	3.11	581	3.40	608	3.95
529	3.45	555	3.18	582	3.48	609	3.90
530	3.13	556	3.23	583	3.20	610	3.11
531	3.27	558	3.33	584	3.64	611	2.97
532	3.47	559	2.93	585	3.50	612	3.43
533	3.69	560	2.86	586	3.30	613	3.23
534	2.72	561	3.36	588	3.00	614	3.40
535	3.00	562	3.39	589	3.78	615	2.77
536	2.79	563	2.65	590	3.34	616	3.11
537	3.43	564	3.40	591	3.40	617	3.16
538	2.81	565	3.00	592	3.29	618	3.52
539	3.15	566	2.74	593	3.39	619	3.00
540	3.12	568	3.80	594	2.93	620	3.02
541	3.47	569	3.06	595	3.81	621	2.17
542	3.02	570	2.79	596	3.60	622	3.28

TABLE XXII.—*Twenty highest of 100 Early Six Weeks tuber lines when ranked on 3-year average numerical production of marketable tubers per hill* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
***608**	**3.95**	*568	3.80	***549**	**3.63**	***607**	**3.50**
***577**	**3.95**	*589	3.78	*596	3.60	582	3.48
609	**3.90**	*533	3.69	***618**	**3.52**	**532**	**3.47**
***604**	**3.85**	***548**	**3.65**	***551**	**3.50**	541	3.47
***595**	**3.81**	***584**	**3.63**	*585	3.50	***603**	**3.47**

[a] The lines starred also appear among the 20 highest-yielding when ranked on 3-year average production by weight. Thirteen of these lines (in bold-face type) have uniformly good vine characteristics; the other 7 lines contained plants suggesting degeneration. Average of group, 3.65 tubers per hill.

TABLE XXIII.—*Twenty lowest of 100 Early Six Weeks tuber lines when ranked on 3-year average numerical production of marketable tubers per hill* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
*621	2.17	*573	2.70	*527	2.79	*576	2.84
*518	2.41	*534	2.72	**536**	**2.79**	524	2.86
*545	2.41	*566	2.74	*570	2.79	**560**	**2.86**
*563	2.65	**543**	**2.77**	*538	2.81	578	2.86
*520	2.69	615	2.77	**519**	**2.84**	**526**	**2.90**

[a] The lines starred also appear among the 20 lowest yielding when ranked on 3-year average production by weight. The lines printed in bold-faced type appear among the 40 chosen in 1918 as having good vine characteristics. Average of group, 2.71 tubers per hill.

TABLE XXIV.—*Yields in 1918 of 40 Early Six Weeks tuber lines chosen upon 1918 vine characteristics alone as the best of the 100 lines of this variety* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
517	19,513	*549	24,391	569	20,210	601	19,048
519	17,654	*551	25,553	571	21,139	*604	21,516
*522	19,804	*552	25,553	575	19,977	*605	20,442
*526	20,293	*554	20,907	*577	19,513	*607	18,584
*529	18,351	*558	20,049	*580	21,271	*608	22,005
*532	18,584	560	20,538	*584	19,071	*609	21,516
536	18,119	*561	29,502	*591	20,907	610	16,261
540	19,977	*562	27,873	*594	17,654	*618	19,048
543	22,300	564	19,048	*595	21,027	620	18,119
*548	25,320	565	20,907	600	17,654	*622	19,358

[a] The 26 lines starred also appear among the 40 highest-yielding when ranked on the 3-year average tuber production by weight. The others have very good records for the 3-year period. Average of group, 20,713 pounds per acre.

The vine growth of the other 6 lines is reported in the following 1918 field notes:

LINE NO.	REMARKS.
568.	A little lacking in color but fairly vigorous.
589.	A very good type with possible exception of first unit.
533.	First unit light colored and burning; other plants green and vigorous.
596.	A very good green type; first two hills lacking in vigor, but this is possibly due to soil.
585.	Type fair with exception of last unit, which shows some burning.
582.	A light-colored, burning type.
541.	A good green type with exception of first unit, which is distinctly lighter and burning.

In Table XXIV data are assembled to show the relation between good vine characteristics and tuber production in Early Six Weeks. The 40 lines with best vine characteristics gave an average yield of 20,713 pounds per acre in 1918, while the 41 heaviest-yielding lines of 1918 grouped in Table XXV averaged 21,350 pounds. The 1918 average of the 100 Early Six Weeks lines was 17,344 pounds of marketable tubers per acre. In this variety vine growth is almost as reliable as yield records in pointing out high-yielding lines. The 3-year average yield of the 40 lines in Table XXIV was 19,515 pounds per acre, while the 40 lines ranking highest on 3-year average tuber production by weight yielded during the same period an average of 20,455 pounds. Will it pay to keep yield records when 40 per cent of the heaviest-yielding lines chosen with the aid of 3 years' data do not produce 1,000 pounds per acre more than do 40 per cent selected in less than 2 hours upon vine characteristics alone?

TABLE XXV.—*Forty-one highest-yielding of 100 Early Six Weeks lines in 1918* [a]

Line No.	Yield.	Line No.	Yield.	Line No.	Yield.	Line No.	Yield.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*
561	**29,502**	**604**	**21,516**	**560**	**20,538**	550	19,745
562	**27,873**	**609**	**21,516**	**605**	**20,442**	**517**	**19,513**
551	**25,553**	525	21,271	**526**	**20,293**	**577**	**19,513**
552	**25,553**	533	21,271	**569**	**20,210**	**622**	**19,358**
548	**25,320**	**580**	**21,271**	586	20,210	**584**	**19,071**
549	**24,391**	**571**	**21,139**	589	20,132	539	19,048
546	22,765	**595**	**21,027**	**558**	**20,049**	**564**	**19,048**
531	22,713	**554**	**20,907**	**540**	**19,977**	585	19,048
543	**22,300**	**565**	**20,907**	**575**	**19,977**	**601**	**19,048**
608	**22,005**	**591**	**20,907**	**522**	**19,804**	**618**	**19,048**
541	21,603						

[a] The 31 lines printed in bold-face type also appear in Table XXIV. This leaves 10 of these high-yielding lines with poor vine characteristics. Average of group, 21,350 pounds per acre.

CONCLUSIONS

The data presented, so far as the author is able to judge, do not furnish very strong evidence of the presence of high-yielding lines within the common population of the varieties studied. The real test of the existence of such lines is ability to maintain a high-yielding progeny by indiscriminate mass selection.

Short performance records are fairly reliable in eliminating lines with low-yielding tendencies, but they are not so reliable as a basis upon which to select plus variations if such really exist.

If degenerate tendencies exist within certain clonal lines and not in others, short performance records are of little value in eliminating the undesirable lines.

Degenerate individuals appear with such persistent regularity within line selections as to become a real stumblingblock. If there are no exceptions to this rule, before a hill or tuber line can be increased to a point where it is of real value in commercial potato production it is almost certain to contain degenerate types which soon reduce its yielding power to that of the common population of the variety.

The data presented will not justify an indorsement of the plan of clonal line selection as a practical method of potato-seed improvement. This does not mean that the hill-selection method of choosing potato seed is without merit. Generally speaking, high-yielding hills selected upon production by weight will produce the following season a high-yielding progeny. It does mean, however, that to be effective hill selection becomes an annual task. I believe there is a more practical method of potato-seed improvement.

Since certain vine characteristics are so closely correlated with yields, selection based on vine development alone promises to be more reliable than selection based on tuber production either by weight or number, and much more practical.

At present, selection based chiefly on vine characteristics seems to be the only hope in dealing with degeneration. The success of such selection is measured by one's ability to identify intermediate types as well as typical curlydwarf degenerates.

A special seed plot in which the seed pieces from each tuber are planted in consecutive hills promises to afford the best solution of the problems of degeneration and the maintenance of high-yielding variety populations.

Seed for such a plot may be selected in one of two ways. Especially vigorous hills may be marked in the field during the growing season, and the crop from these may be dug and used for planting the special seed plot of the following season, or seed may be selected in the field at digging time or from the bin. The first method will insure the greater return from the first seed plot, especially if the field from which the seed is selected contains a large percentage of degenerate plants. In selecting seed in the field after the digger or from the bin, one may to a certain extent avoid degenerate types by observing certain tuber characteristics. (1) Choose seed tubers rather above the average size for the variety. (2) Select those that are long rather than short for the variety and with both ends full and rounded, not pointed. (3) Choose those that are oval rather than round in cross section, or, in other words, flattened tubers. (4) Pick tubers with conspicuous and moderately deep eyes.

The seed plot can best be planted by hand. The rows should be spaced the usual distance apart and the hills placed 12 or 15 inches apart in the row. On good, fertile, irrigated land, where the recommendations in regard to thinning are to be carried out, the hills should be spaced at 12 or even 10 inches apart. The tubers should be taken to the field whole and then cut as planted. The seed pieces may be cut rather small if seed is not abundant. Single-eye seed pieces weighing from ½ to 1 ounce will give just as good results as larger pieces. These are conveniently planted with a hoe, and if small should not be covered over 3 inches deep. Each tuber is cut by itself, and the pieces are dropped in consecutive hills. Not only is it important to have the hills from each tuber in a group, but it is desirable to have these groups marked off one from the other. This may be accomplished in several ways. A good way is to drop a hill of corn between the groups. The important point, however, is to have the hills from each tuber in a group. This is the only way if intermediate types are to be eliminated from the seed plot by roguing. Mixtures are also easily detected where the hills are in tuber groups.

The seed plot should be thinned by removing all but one stalk from each hill. Thinning should be done as soon as the vines are large enough to pull, usually from five to six weeks after planting. Proper comparisons can best be made between hills with a uniform number of stems, and this is the real object of thinning. But single-stemmed hills also produce tubers of a more uniform size, and this is desirable, especially if the seed stock is to be offered for sale. Regardless of the merits of the case, the public commonly thinks of good potato seed as uniform-sized stock.

Roguing the seed plot is the most important step in the production of good seed. This consists in going over the field several times during the season and removing undesirable hills. In the first place, there may be variety mixtures in the seed plot. These mixtures are detected chiefly by variations in foliage, color of blossoms, amount of blossoms produced, and dates of ripening. There will also be some weak and degenerate types and diseased hills to be removed. The plot should first be gone over about blooming time, as variety mixtures are then very likely to be most conspicuous. A group of hills may show blossoms that are off type in color, or a certain group of hills may bloom more or less than the other plants in the plot. These hills should be dug and the tubers removed from the field. A little later the plot should be gone over again to catch hills lacking in vigor or infected with disease. In early varieties, this examination should be made just about the time the most vigorous vines show signs of maturing. At this time some vines will be found fully mature. This premature ripening is probably brought on by disease, and the hills should be removed. Such hills most frequently appear at random, but occasionally all the hills from a seed tuber may be diseased. In looking for weak plants, the hills from each tuber should be studied as a group. Weak hills will show a more crinkled foliage and usually less vigorous vines. It is well to remember that the intermediate types are the real trouble makers. They are usually as vigorous as normal hills, but show a slight crinkling of the foliage and are very often of a lighter shade of green.[1] In looking for these weak groups it is best not to work too near the row being examined. First look each row over at close quarters and then from two or three rows distant. In roguing out late varieties, the work must always be done before the vines are touched with frost. Remember that in roguing the tubers as well as the vines must be dug and removed from the seed plot.

If the seed plot has been carefully rogued, the entire crop may be saved for seed. Occasionally a group of hills may produce tubers of poor form, and these may be discarded. The small seed from such a seed plot is just as satisfactory as the large, and in the great majority of cases variations in form are nothing more than fluctuations and as such are not transmitted to the following crop.

In many instances the improvement secured by growing a variety in a special seed plot of this kind for one season may be apparent for two or three years after returning to the practice of selecting seed at random from the field at digging time or from the bin; but permanent improvement can be maintained only by continuing the special seed plot year after year. With most varieties it is allowable, if the roguing is carefully done, to increase the seed secured from the seed plot by planting it in a certain part of the commercial field and then saving

[1] WHIPPLE, O. B. DEGENERATION IN POTATOES. Mont. Agr. Exp. Sta. Bul. 130, 29 p., 16 fig. 1919.

from this part of the field seed for the entire acreage the following season. But if one is not absolutely sure he can pick out the intermediate types in roguing, this practice may prove disappointing. Once the special seed plot is established, it may well be continued from year to year, the seed for the special seed plot of each year being selected from the seed plot of the year before. It is even advisable to go into the special seed plot and mark especially promising groups of hills to be dug to furnish seed for the seed plot of the following year.

OCCURRENCE OF THE FIXED INTERMEDIATE, HORDEUM INTERMEDIUM HAXTONI, IN CROSSES BETWEEN H. VULGARE PALLIDUM AND H. DISTICHON PALMELLA[1]

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INTRODUCTION

The cultivated barleys belong to the genus Hordeum and are characterized by the presence of three single-flowered spikelets at each node of the rachis. The floret of the central spikelet develops a normal kernel in all forms of barley. The lateral florets, on the other hand, may develop normal or undersized kernels or may be sterile or even abortive. In classifying the varieties, Harlan (*2*)[2] recognized four species, basing them on the degree of fertility in the lateral florets. Varieties of three of these species are concerned in the data presented herein. In all varieties mentioned, the central florets are long-awned. The 6-rowed parents in all hybrids belonged to the botanical variety *H. vulgare pallidum*, and include Manchuria, S. P. I. No. 20375, Sex-radigt, Odessa, Reid Triumph, Surprise, and a hybrid 6-rowed × 2-rowed barley. The lateral as well as the central florets of these varieties are long-awned and produce well-developed kernels.

The 2-rowed parents all belong to the variety *H. distichon palmella*. The central florets are long-awned, while the lateral ones are awnless with rounded tips and are sterile. Of the varieties mentioned in the text, Svanhals, Garton, and Primus belong to this group. The intermediates are products of hybridization, and the selections are unnamed. All, however, belong to the botanical variety *H. intermedium haxtoni*. In these the central florets are long-awned and produce normal kernels, while the lateral florets are awnless, as in the 2-rowed barleys, but fertile, producing undersized but viable kernels. The percentage of fertility in these spikelets is not so high as in the 6-rowed, but neither are they infertile, as are the 2-rowed. This form, obviously intermediate in character between the 6-rowed and 2-rowed barleys, has proved to be constant and is as distinct in its genetic behavior as either the 6-rowed or the 2-rowed forms.

The history of the intermediate barleys is very interesting, but not always clear. The first recorded observation found is that of John Haxton (*3*) in Scotland. In Morton's Cyclopedia of Agriculture of 1851 he mentions having observed such a plant in a field of "Bere." At the time

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[1] This paper is based upon experiments conducted cooperatively by the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, and the Minnesota Agricultural Experiment Station.

[2] Reference is made by number (italic) to "Literature cited," pp. 590–591.

Journal of Agricultural Research,
Washington, D. C.
ux

Vol. XIX, No. 11
Sept. 1, 1920
Key No. G–204

of this description he obviously had the heterozygous intermediate or a mixture of this and the homozygous intermediate, since he obtained all types from the seeding. Later, the homozygous form seems to have been isolated. In 1883, Drechsler of Göttingen sent Rimpau an intermediate which he had found in a field of *H. distichon palmella zeocriton* and which apparently bred true from the time of its discovery. Both Rimpau (*6*, *7*) and Körnicke (*4*) observed the intermediate. According to Körnicke's statement of 1885, he found the intermediate as an accidental hybrid in a field of 2-rowed winter barley. At first the selection was heterozygous, but, according to the statement of his son (*5*), in 1908, it later became constant. Both Rimpau and Körnicke made mass selections which evidently included heterozygous forms, at least at first. It is probable that homozygous types were eventually obtained.

These four cases of probable isolation of the fixed intermediate all occurred before 1900 and, therefore, before the importance of plant selections in hybrids was generally recognized. It is worthy of note that all four were instances where accidental hybrids were observed, rather than the products of any of the numerous crosses made by those investigators.

The history since 1900 is more surprising than that previous to 1900. The modern methods of breeding lead to the direct and ready isolation of this type, yet, so far as the authors know, it has not been reported. Since 1900, indeed, two plant breeders who have worked extensively with barley have assumed that a fixed intermediate does not occur in crosses between 6-rowed and 2-rowed barleys. Von Tschermak (*8*) says as late as 1914 that the intermediate form with fertile lateral florets is heterozygous and, therefore, is never constant. Biffin (*1*), while not so sweeping in his statement, must have held a similar view. In 1907, he reported nine crosses in which a homozygous intermediate might occur. From the F_2 progeny of one of these he selected a considerable number of intermediates of two types and planted them. All proved to be heterozygous. He did not test the progeny of the other crosses but assumed that they would behave in the same way. In the discussion he then states:

The heterozygote, therefore, of forms with hermaphrodite staminate lateral florets is potentially hermaphrodite and of the type known to systematists as *H. intermedium*.

In 1907 J. H. Wilson (*9*) reported an F_2 generation of Standwell × Bere, in which he made the following observation:

Examples occurred in which the grains of all six rows were fully developed, but the lateral ones were without awns.

In this case Mr. Wilson probably noticed the homozygous type. It is interesting that he should have used as the 6-rowed parent the variety of barley in which Haxton found the first recorded intermediate.

The observations of the senior author in these studies extend over the past 10 years. In the summer of 1909 he made a large number of hybrids on the grounds of the Minnesota Agricultural Experiment Station. A con-

siderable number of these were between 2-rowed and 6-rowed parents. In 1910 the F_1 generation was grown, and in 1911 the F_2 generation. In the F_1 generation of 1910 the heterozygous intermediate was very vigorous, and a considerable number of selections were grown in 1911 from the small lateral kernels to see if they would produce vigorous plants. In the F_2 generation it was apparent that there were intermediates present which differed from those of 1910, and 56 selections of different types of intermediates were grown in 1912. These came from 12 different crosses and included the progeny of combinations of 10 different 2-rowed and 7 different 6-rowed parents. A number of these proved to be homozygous, and others were isolated from the F_3 generation by further selection. Unfortunately, the records of 1912 are incomplete, and the total number of homozygotes obtained can not be determined. It is also impossible to establish the complete list of crosses from which fixed intermediates were obtained. Beyond all question, from one to five fixed intermediates were obtained from each of five different crosses. These crosses involve three different 2-rowed and five different 6-rowed parents. In these cases original material or complete records of the progeny are still at hand. The crosses were as follows: S. P. I. No. 20375 × Svanhals, Surprise × Primus, Primus × (2-rowed × 6-rowed), Garton 2-rowed × Sex-radigt, and Manchuria × Svanhals. There is a definite statement in the field records that a selection of *zeocriton* × Manchuria and another of Chevalier × South African were fixed intermediates, but there are neither specimens nor progeny records to confirm these statements.

It will be seen that in the five crosses where the evidence is complete the 2-rowed parents were dense-spiked. Aside from the fact that those which have been preserved came from such crosses, there is no evidence in the data now at hand that indicates inability to secure intermediates from crosses in which both parents are lax-spiked. The common varieties of lax 2-rowed barleys have less vigorous lateral florets than the common varieties of dense 2-rowed barleys. It is possible that the progeny of crosses where the lax forms were used would be lower in fertility and the intermediates correspondingly less conspicuous. Hence, they would be less desirable and less likely to be retained as specimens.

In 1915, after the junior author became connected with the Minnesota Agricultural Experiment Station, it was decided to repeat one of the crosses from which fixed intermediates had been secured, in order to determine the inheritance and, if possible, to discover an explanation of the occurrence of this form. By making crosses and growing an occasional generation in the greenhouse in Washington in the winter and sowing the seed in Minnesota in the spring several generations have been studied since that date. The cross chosen for this purpose was Manchuria × Svanhals. The F_2 and F_3 generations are reported in detail. Other crosses were studied in which no intermediates were produced; but since the data are negative, they have not been included,

although reference is made in the discussion to them and their significance.

OCCURRENCE OF H. INTERMEDIUM AND OTHER SEGREGATES IN THE PROGENY OF A CROSS OF MANCHURIA AND SVANHALS BARLEYS

The Manchuria parent in this cross is a selection of the common 6-rowed barley of the northern Mississippi Valley. The side florets are fertile and long-awned. The Svanhals parent is a well-known 2-rowed variety with long-awned, fertile, central florets and awnless, rounded, sterile lateral ones. The Manchuria is illustrated in Plate 103, C, and the Svanhals in Plate 104, A. This cross was made in the Washington greenhouse in the spring of 1917, and the F_1 generation was grown the same season at the University of Minnesota. In the fall of 1917, 100 of these F_1 seeds were sown in pots in the Washington greenhouse. Of these, only 87 matured as F_2 plants in the spring of 1918. As soon as the grain was sufficiently mature to harvest seed was again sent to Minnesota, where the F_3 generation was grown.

PHENOTYPIC CLASSES IN THE PROGENY

The data on the F_3 generation are reported in Table I, which needs considerable explanation. In the first place, the material itself is not simple. It is far from easy for a reader unfamiliar with barley to visualize six classes of segregates. Added to this difficulty is the fact that the F_3 classifications are of varying accuracy and are phenotypic in character. The phenotypic classes of the table give a misleading impression by overemphasizing the importance of the amount of fertility present. There are other characters than fertility which have much significance in the genetic groups. Fertility, however, is a definite, tangible, measurable condition, and the phenotypic classes founded on it are usable. In some instances the phenotypic classes of the F_3 generation coincide with the genetic classes, while in others a phenotypic class contains more than one genetic class. There is a certain amount of unavoidable confusion in describing both phenotypic and genetic classes at the same time. For this reason, until the genetic classes are established the plants exhibiting similar phenotypic classes in their progeny are placed together and referred to as genetic groups. It must be remembered in studying the table that the main object of the F_3 classification was to determine the genetic classes of the F_2 generation. It is well also to recall at this time that all classifications in this paper are based on the nature of the lateral florets, and to avoid endless repetition the modifying adjective is frequently omitted. In such cases the terms sterile, awn-pointed, high fertility, etc., refer to the lateral florets only.

Table I represents the data as taken. The first two columns of the table contain the identification numbers and the description of the F_2 plants. In the remaining columns the F_3 progeny of these plants are classified. These progeny fall into two major divisions, in one of which

all the kernels are of normal size, while in the other they are subnormal or absent. This second division is separated into plants which have lateral florets with awned or awn-pointed lemmas and plants in which the lemmas of the lateral florets are awnless and more or less rounded. Further subdivisions were based on the percentage of fertility of the lateral florets. The nature of the six resulting classes is illustrated in Plates 103 and 104. It is readily apparent in Plate 103 that the three classes with awned or awn-pointed lemmas on the lateral florets are easily separated. It is just as apparent in Plate 104 that the accident of season or nutrition can easily affect the classification of the segregates with rounded lemmas. Errors of classification in this case happen to be unimportant, for, as previously stated, the object of the F_3 classification is only to determine the nature of the F_2 parent. This is made evident in all cases by the classification used. To make this clear, one of the findings must be anticipated. Of the six classes in which the F_3 plants are divided, three are of special importance in the interpretation. These are the fully fertile long-awned, the high-fertility awnless, and the no-fertility awnless classes. These represent the 6-rowed, the *intermedium*, and the 2-rowed barleys. In all cases the classification is sufficiently accurate to determine which of these classes are to be found in the progeny of each F_2 plant.

TABLE I.—*Classification of 87 F_2 plants and their F_3 progeny in a cross between Manchuria and Svanhals barleys according to the nature of their lateral florets*

GROUP 1, PLANTS WHICH GAVE ONLY 6-ROWED PROGENY

F_2 parent No.	F_2 parent type.	Number of individuals in F_3 progeny, by classes.						Total.
		Kernels normal size, lemmas long-awned, fully fertile (6-rowed).	Kernels subnormal in size or absent.					
			Lemmas awned or awn-pointed.		Lemmas awnless.			
			High fertility (80–100 per cent).	Low fertility (0–79 per cent).	Fertility 5–100 per cent (*intermedium*).	Fertility less than 5 per cent.	Fertility none (2-rowed).	
2	6-rowed	20						20
7	....do	24						24
11	....do	20						20
15	....do	21						21
23	....do	19						19
33	....do	24						24
38	....do	20						20
41	....do	45						45
44	....do	23						23
45	....do	19						19
49	....do	21						21
50	....do	20						20
60	....do	44						44
70	....do	23						23
72	....do	22						22
75	....do	18						18

TABLE I.—*Classification of 87 F_2 plants and their F_3 progeny in a cross between Manchuria and Svanhals barleys according to the nature of their lateral florets*—Con.

GROUP 1, PLANTS WHICH GIVE ONLY 6-ROWED PROGENY—continued.

F_2 parent No.	F_2 parent type.	Number of individuals in F_3 progeny, by classes.						Total.
		Kernels normal size, lemmas long-awned, fully fertile (6-rowed).	Kernels subnormal in size or absent.					
			Lemmas awned or awn-pointed.		Lemmas awnless.			
			High fertility (80–100 per cent).	Low fertility (0–79 per cent).	Fertility 5–100 per cent (*intermedium*).	Fertility less than 5 per cent.	Fertility none (2-rowed).	
79	.....do.....................	20	......	......	......	......	......	20
82	.....do.....................	45	......	......	......	......	......	45
88	.....do.....................	34	......	......	......	......	......	34
94	.....do.....................	21	......	......	......	......	......	21
97	.....do.....................	19	......	......	......	......	......	19
100	.....do.....................	15	......	......	......	......	......	15
GROUP 2, PLANTS WHICH GAVE 6-ROWED AND INTERMEDIUM BUT NO 2-ROWED SEGREGATES								
29	80 per cent fertile, awned....	12	23	......	12	......	......	47
62	25 per cent fertile, awned....	18	20	......	6	......	......	44
64	90 per cent fertile, awned....	16	20	......	10	......	......	46
85	33 per cent fertile, awned....	7	15	2	10	......	......	34
98	90 per cent fertile, awned....	17	13	......	10	......	......	40
99	.....do.....................	7	23	1	5	3	......	39
37	5 per cent fertile, awnless....	7	30	......	6	......	......	43
GROUP 3, PLANTS WHICH GAVE 6-ROWED, INTERMEDIUM, AND 2-ROWED SEGREGATES								
12	5 per cent fertile, awned.....	15	14	8	0	0	4	41
17	3 per cent fertile, awned.....	11	12	7	0	1	10	41
19	None fertile, awned..........	9	6	4	1	0	3	23
25	.....do.....................	15	9	11	2	1	11	49
26	.....do.....................	14	16	10	0	1	9	50
28	.....do.....................	8	13	12	3	0	8	44
31	.....do.....................	10	19	5	3	0	8	45
32	.....do.....................	16	7	13	0	0	10	46
39	.....do.....................	9	12	13	1	2	11	48
40	.....do.....................	12	13	8	1	1	12	47
46	.....do.....................	12	16	12	2	0	5	47
48	.....do.....................	14	5	14	0	1	5	39
55	.....do.....................	10	14	4	3	1	15	47
56	9 per cent fertile, awned.....	10	16	4	7	1	8	46
58	None fertile, awned..........	17	15	3	4	0	5	44
59	.....do.....................	12	17	6	1	2	11	49
69	.....do.....................	24	6	13	1	2	4	50
71	13 per cent fertile, awned....	13	6	3	1	0	3	26
74	12 per cent fertile, awned....	10	22	0	0	4	8	44
76	None fertile, awned..........	11	8	15	1	3	7	45
77	.....do.....................	9	6	14	1	1	8	39
78	.....do.....................	11	1	13	1	0	19	45
81	.....do.....................	16	7	16	1	0	7	47
84	.....do.....................	15	11	11	1	0	6	44
96	.....do.....................	7	10	15	0	0	10	42

TABLE I.—*Classification of 87 F_2 plants and their F_3 progeny in a cross between Manchuria and Svanhals barleys according to the nature of their lateral florets*—Con.

GROUP 4, PLANTS WHICH GAVE 6-ROWED AND 2-ROWED BUT NO INTERMEDIUM SEGREGATES

F_2 parent No.	F_2 parent type.	Number of individuals in F_3 progeny, by classes.						Total.
		Kernels normal size, lemmas long-awned, fully fertile (6-rowed).	Kernels subnormal in size or absent.					
			Lemmas awned or awn-pointed.		Lemmas awnless.			
			High fertility (80–100 per cent).	Low fertility (0–79 per cent).	Fertility 5–100 per cent (*intermedium*).	Fertility less than 5 per cent.	Fertility none (2-rowed).	
9	None fertile, awned	5	......	15	......	......	4	24
34	.....do	17	......	19	......	......	9	45
35	.....do	6	......	14	......	......	4	24
36	.....do	7	......	26	......	......	11	44
47	.....do	11	......	25	......	......	11	47
54	.....do	12	......	25	......	......	10	47
65	.....do	13	......	15	......	......	19	47
68	.....do	12	......	16	......	......	15	43
83	.....do	7	......	21	......	......	10	38
86	.....do	11	......	19	......	......	13	43

GROUP 5, PLANTS WHICH GAVE ONLY INTERMEDIUM FORMS

10	10 per cent fertile, awnless	......	......	......	47	......	......	47
16	None fertile, awnless	......	......	......	39	7	......	46
18	.....do	......	......	......	44	......	......	44
30	.....do	......	......	......	41	5	......	46
66	.....do	......	......	......	38	......	......	38
93	.....do	......	......	......	45	15	......	60
95	20 per cent fertile, awnless	......	......	......	35	......	......	35

GROUP 6, PLANTS WHICH GAVE INTERMEDIUM AND 2-ROWED BUT NO 6-ROWED SEGREGATES

5	None fertile, awnless	......	......	......	7	......	40	47
6	.....do	......	......	......	9	......	38	47
14	.....do	......	......	......	10	10	30	50
15	.....do	......	......	......	8	9	24	41
24	.....do	......	......	......	8	1	11	20
27	.....do	......	......	......	6	4	36	46
42	.....do	......	......	......	8	5	30	43
51	.....do	......	......	......	12	3	33	48
67	.....do	......	......	......	11	0	32	43
80	.....do	......	......	......	4	0	42	46
92	.....do	......	......	......	10	4	29	43

GROUP 7, PLANTS WHICH GAVE ONLY 2-ROWED FORMS

4	None fertile, awnless	......	......	......	......	......	46	46
8	.....do	......	......	......	......	......	46	46
22	.....do	......	......	......	......	2	22	24
73	.....do	......	......	......	......	......	45	45
80	.....do							

GENETIC GROUPS INDICATED BY THE PROGENY CLASSES

The F_2 plants in Table I are arranged in groups according to the segregation shown in the F_3 generation.

Group 1 consists of plants which gave only 6-rowed progeny in the F_3 generation. Since the parents were 6-rowed, the plants in this group are unquestionably homozygous for this character.

Group 2 consists of plants which gave 6-rowed and *intermedium* but no 2-rowed forms. The F_2 plants evidently correspond to those in the high-fertility column of the F_3 classification The classification of the high-fertility group is readily made and is highly accurate. Since this group gave 6-rowed, high-fertility, and *intermedium* segregates in approximately a 1 to 2 to 1 ratio, it is safe to assume that the high-fertility plants are heterozygous for 6-rowed × *intermedium* which differ by a single factor.

Group 3 gave all three homozygous classes and all heterozygous classes as well. From this it is obvious that this group is comparable to the F_2 generation and is heterozygous for the same factor differences as separate the original 6-rowed × 2-rowed forms.

Group 4 gave 6-rowed, low-fertility awned, and 2-rowed forms in approximately a 1 to 2 to 1 ratio. Since this low-fertility awned corresponded in appearance to the F_2 parents, it would seem that this group also was heterozygous for 6-rowed × 2-rowed, which in this instance, however, represents a single factor difference. It gave no *intermedium* forms, nor did it give the high-fertility awned or the low-fertility awnless forms. In other words, the *intermedium* character in both its homozygous and its heterozygous aspects was absent. The fact that this group as well as group 3 is heterozygous for 6-rowed × 2-rowed, even though more factors are involved in one case than the other, can be reconciled only on the basis that there are two types either of the 6-rowed or of the 2-rowed forms, only one of which carries the possibilities of producing *intermedium* forms.

Group 5 consists entirely of F_2 plants which gave only *intermedium* forms in the F_3 generation. In other words, out of 87 F_2 plants there were 7 homozygous for the the type which has been noticed so rarely in barley studies and whose very occurrence has been questioned so frequently. That the F_2 plants showed no higher fertility was doubtless due to their being grown in the greenhouse. Those plants of the F_3 generation falling in the low-fertility class merely show the variation which exists. They do not cast any doubt on the genetic character of the F_2 parents, because there were no 2-rowed segregates from any of the seven F_2 plants.

Group 6 gives homozygous intermediates, low-fertility awnless, and no-fertility awnless. The numbers in the classes are not significant in this case, for some sterile spikes of *intermedium* and the larger part of

one heterozygous group are included with the homozygous 2-rowed as phenotypes. The F_2 plants in group 6, however, unquestionably are heterozygous for *intermedium* × 2-rowed, a single main factor difference separating the *intermedium* and 2-rowed forms.

Group 7 may be considered as composed of plants homozygous for 2-rowed, since with the exception of the two plants noted there was no fertility exhibited in the progeny.

The seven groups just discussed consist of F_2 plants assembled in groups because of their evident similarity of genetic constitution. In other words, these groups are genetic classes in contradistinction to the phenotypic classes of the F_3 generation. In Table II the data on these groups are summarized. The second column of this table gives the genetic constitution of each group. Except for the subdivisions of group 1, this classification was verified in the F_3 generation. In the third column a hypothetical formula is suggested for each group. These formulas are based on a 2-factor difference between the 6-rowed and the 2-rowed forms. The Manchuria 6-rowed parent is supposed to possess both factors, while in the 2-rowed Svanhals parent both supposedly are lacking.

TABLE II.—*Summary of F_2 plants of the cross between Manchuria and Svanhals*

Group No. as in Table I.	Genetic constitution as shown by progeny.	Hypothetical formulas.	Expected Mendelian ratio.	Expected number on basis of 87 plants.	Number obtained in 87 plants.	Description of F_2 plants.
1	Homozygous for 6-rowed.....	AABB	1			
1	Heterozygous for 6-rowed × regressive 6-rowed.	AABb	2	22	22	Lateral florets long-awned, fully fertile, kernels normal size.
1	Homozygous for regressive 6-rowed.	AAbb	1			
2	Heterozygous for 6-rowed × *intermedium*.	AaBB	2	11	7	Lateral florets short-awned, highly fertile, kernels small.
3	Heterozygous for 6-rowed × 2-rowed.	AaBb	4	22	25	Lateral florets awn-pointed to short-awned, no fertility to low fertility.
4	Heterozygous for regressive 6-rowed × 2-rowed.	Aabb	2	11	10	Lateral florets awn-pointed to short-awned, no fertility.
5	Homozygous for *intermedium*.	aaBB	1	5	7	Lateral florets enlarged, awnless, low fertility to no fertility, kernels small.
6	Heterozygous for *intermedium* × 2-rowed.	aaBb	2	11	11	Lateral florets awnless, somewhat enlarged, no fertility.
7	Homozygous for 2-rowed.....	aabb	1	5	5	Lateral florets small, awnless, no fertility.

This hypothesis accounts for the results very well. The 2-rowed segregates of group 7 are homozygous in the absence of both factors. The fixed intermediates or *H. intermedium* forms of group 5 are homozygous for the presence of one factor and for the absence of the other. The heterozygous groups, 2, 3, 4, and 6, are all heterozygous for one or both factors. Groups 2, 4, and 6, which are heterozygous for only one factor, give F_3 progeny of limited distribution. Group 3, which is heterozygous for both factors, gives all classes in the F_3 generation.

Group 1 is the only group offering any complications, and these are of no particular complexity. If the 2-factor hypothesis is tenable, group 1 must include three different classes of 6-rowed forms, two of which are homozygous. If the factor AA is considered epistatic to the factor BB, the three classes of group 1 become phenotypic for 6-rowed and may be considered as a single class. In genetic constitution, however, the homozygous 6-rowed segregate AAbb differs from the parent 6-rowed AABB; and, inasmuch as the BB factor has been lost, the form AAbb is referred to here as a regressive 6-rowed. If this regressive 6-rowed AAbb were crossed on the Svanhals parent aabb, there would be no possibility of securing the homozygous intermediate aaBB. Heterozygous types corresponding to such a cross probably are found in group 4, which is supposed to be heterozygous for this regressive 6-rowed AAbb × the 2-rowed aabb. On the other hand, group 3 is heterozygous for the parent 6-rowed AABB × the 2-rowed aabb.

It will be seen in Table II that the plants obtained in each group came very close to the expectancy. The numbers of 6-rowed and 2-rowed forms produced coincide exactly with the expected numbers, while the number of fixed intermediates is only two greater than in the calculated ratio.

The nature of the factors is better discussed in connection with the description of the genetic classes which is given in Table II. It will be seen from the table that except in group 1 these various classes differ in appearance as well as in genetic constitution. In some instances the separations are easily made on appearance alone, while in others only a part of the plants belonging to a group can be easily identified. The first four groups have lateral florets, the lemmas of which bear awn points or awns of varying lengths. Group 1, of course, presents no difficulties, for 6-rowed segregates are unmistakable. Group 2 is almost as definite, for there are no other high-fertility segregates with small-kerneled, awn-pointed lateral florets. Group 3 is readily separated from group 2 by the lower fertility of the individuals in group 3. The sterile individuals of group 3, however, are easily confused with the individuals of group 4. Probably 80 per cent of such plants in group 3 can be identified by the more obtuse lemma tip on the lateral florets. Groups 5, 6, and 7 differ from the other groups in the absence of awns on the rounded tips of the lateral florets. These conditions are not absolute, in that an occasional floret may possess an awn. In this case, however, other florets on the same spike have the characteristic rounded obtuse tips. Group 5 is characterized by the possession of lateral florets which, even when sterile, are larger than those of the 2-rowed. Under field conditions higher fertility probably would have been present in the members of this group. When the F_2 material was being studied, it was possible, however, to isolate the sterile spikes of *intermedium* forms by inspection. In group 6 the lateral florets of many individuals are

obviously larger than in the 2-rowed segregates, but as a rule they are not so large as in group 5. Groups 6 and 7 can be accurately separated only by the breeding test.

It will be seen, then, that although fertility is the basic distinction, it is expressed in other ways than in the production or nonproduction of kernels. Indeed, the percentage of fertility probably varies more with environment than do the morphological differences. Such variation, however, does not imply any lack of reliability of the fertility factors.

According to the factor hypothesis, the first four groups have the inherent possibility of producing 6-rowed segregates. Only plants belonging to these four groups have lateral florets the lemmas of which are awned or awn-pointed. The A factor, either as AA or Aa, is found only in these groups. This factor, then, must be associated with the possibility of awns. When A is homozygous, fully fertile, long-awned florets which develop kernels of normal size are produced. When A is heterozygous, all lateral florets are short-awned or awn-pointed. When homozygous, it is epistatic to B, the spike being normal 6-rowed irrespective of the condition B. When heterozygous, A has little effect on fertility, and the amount of fertility present in this case is in direct relation to B. The lateral florets of AaBB are quite fertile, those of AaBb occasionally so, while those of Aabb as a class are sterile. Aa may have a slight effect on fertility, for AaBB has a higher percentage of fertility than aaBB. The factor BB, then, is a fertility factor which at its highest expression produces a lower percentage of fertility than AA. It is not accompanied by the presence of awns. The lateral florets under its stimulation produce undersized kernels, the largest form of floret seeming to be associated with AA.

INDICATION OF A THIRD FACTOR

The presence of a third factor of fertility was first suggested by a study of the data in Table I. Column 2 of that table shows the percentage of fertility of the F_2 parents. In group 2, three plants exhibited a much lower fertility than the other four. Since one of these was abnormal, there were, excluding this plant, two low-fertility and four high-fertility plants. It is difficult to measure the inheritance of these variations in this group. The percentage of fertility of the *intermedium* segregates in the F_3 generation of four lines was studied. The F_3 *intermedium* segregates of the others were missing. Three high-fertility lines gave almost identical fertility of 37+ per cent. One low-fertility line gave 29.5 per cent of fertility. In group 3, five out of twenty-five plants showed some fertility. The F_3 plants were not studied for differences in percentage of fertility.

In group 5, two out of seven plants had fertile lateral florets. In this group the progeny were studied carefully. This is the only group

where this can be done readily, because the others, where the differences in percentage of fertility occur, are heterozygous for one or both main factors. If there is a third factor, the F_2 generation indicates that it is expressed here as a 1 to 3 ratio with the heterozygous forms indistinguishable from those homozygous for the absence of the factor. By the same reasoning, lines 10 and 95 in Table I, which showed fertility, should be homozygous for the presence of the factor and should exhibit a higher percentage of fertility than the progeny of the other five lines. The F_3 progeny of lines 10 and 95 averaged 54.6 and 48.4 per cent of fertility in the lateral florets, while the progeny of the other lines were, respectively, 35.7, 33.2, 30.3, 25, and 17.8 per cent fertile.

The data indicating a third factor in fertility are summarized in Table III. The evidence at hand is not more than an indication of a minor factor, yet the material itself is far more suggestive of such a factor than the evidence.

TABLE III.—*Summary of data indicating a third factor of fertility in the cross between Manchuria and Svanhals*

Group No.	Genetic constitution as shown by progeny.	Hypothetical formulas.	Expected mendelian ratio.	Number of plants in group.	Expected number of plants by subgroups.	Number of plants obtained.
2	Heterozygous for 6-rowed × *intermedium*	AaBBCC	2	6	2	4
		AaBBCc	4		4	
		AaBBcc	2		2	2
3	Heterozygous for 6-rowed × 2-rowed	AaBbCC	4	25	6	5
		AaBbCc	8		13	20
		AaBbcc	4		6	
4	Heterozygous for regressive 6-rowed × 2-rowed	AabbCC	2	10	3	2
		AabbCc	4		5	6
		Aabbcc	2		3	2
5	Homozygous for *intermedium*	aaBBCC	1	7	2	2
		aaBBCc	2		4	5
		aaBBcc	1		2	

DISCUSSION OF RESULTS

FIXED INTERMEDIATE, H. INTERMEDIUM

Since the purpose of this study was to gain a better understanding of the occurrence of *H. intermedium*, this form is of greater interest here than any of the other segregates. From the standpoint of historical and present interest there are three questions which can now be answered. There is no doubt that such forms occur; they have been found to be stable; and in the particular cross reported here in detail the ratio of appearance is approximately 1 to 16.

The stability of this form was established by observations on intermediates obtained from several crosses. The field experiences fit in well

with the 2-factor hypothesis suggested. The stability of the homozygous intermediate has been thoroughly tested. Some of these have been grown since 1912 under widely varying conditions with no indication of reverting to either the 6-rowed or 2-rowed parental type. Many hybrids have been made with the *intermedium* form as one parent. There are complete records of the progeny of crosses on five 6-rowed and on two 2-rowed forms. No 2-rowed segregates appeared among the progeny of the 6-rowed × *intermedium* crosses, and no 6-rowed segregates appeared among the progeny of the *intermedium* × 2-rowed crosses. Every hybrid studied so far indicates that *H. intermedium* has a genetic rank equal to *H. vulgare* or *H. distichon*.

In field culture there is always variation in the amount of fertility present in the lateral florets of the *intermedium* form. This is true even on a single plant. The earlier, better-nourished spikes in some strains may have as high as 90 per cent of the lateral florets fertile. The later spikes of the same plant usually have a diminishing percentage, while the last-appearing may have lateral florets which are entirely sterile. Such variations, however, are the result of variation in nutrition, for their progeny are uniformly *intermedium* in type.

There are variations of another sort in the *intermedium* forms which have more significance. Frequent mention has been made of the fact that the fertility of the different classes may be expected to vary with the parents used. From crosses showing more vigor in the lateral florets of the segregates than those of the Manchuria × Svanhals, very vigorous intermediates may be isolated. From those crosses which show less fertility in the segregates, homozygous intermediates probably may be isolated in which only occasional kernels may be produced. Instances may be possible where a potential intermediate may exhibit no fertility whatever.

The form *atterbergii* shown in Plate 106 is probably an infertile *intermedium* barley. This form is somewhat anomalous in the taxonomy of barley. It has never been grown by the authors, but from the statements of those who have grown it, it appears to have shown no fertility. The illustration is a photograph of a spike presented to the United States Department of Agriculture several years ago by Mr. E. S. Beaven. It has greatly enlarged lateral florets which closely resemble those of spikes of *H. intermedium*, in which potentially fertile lateral florets are sterile because of environment.

REGRESSIVE 6-ROWED FORM

The recognition of the two different forms homozygous for the 6-rowed character offers a field for further investigation. The regressive 6-rowed AAbb is apparently not optically distinguishable from the AABB 6-rowed. There is no method known to the authors of separating these by inspection. In hybrids the regressive 6-rowed form should behave quite

differently. If this regressive type were crossed on the *intermedium* form the results, according to the hypothesis advanced, would not be the same as when the Manchuria is so crossed. The Manchuria × *intermedium* gives 6-rowed, high-fertility, and *intermedium* segregates in a 1 to 2 to 1 ratio in the F_2 generation. The regressive 6-rowed × the *intermedium* form should give all classes, including 2-rowed forms, in the F_2 generation. On the other hand, if the regressive 6-rowed were crossed on the Svanhals, no *intermedium* segregates would be expected. Unfortunately, neither of these crosses has been made, but the latter condition has been met in other crosses. Strains of Odessa and Reid Triumph when crossed on Svanhals produced no intermediates, indicating that the regressive 6-rowed AAbb does occur. The progeny of these crosses segregates in the same way as the group which is heterozygous for the regressive 6-rowed × 2-rowed in Table I. Incidentally, there is evidence that the strains used, of both Reid Triumph and Odessa, originated as selections from a previous hybridization. No evidence is at hand to indicate whether or not the regressive 6-rowed type AAbb occurs elsewhere than in the progeny of hybrids.

Because fixed intermediates have been secured from hybrids in which several old agricultural races of 6-rowed barley were used as one parent, it is assumed that forms such as the Manchuria are the normal 6-rowed forms. It is not known how frequently the regressive types occur among our agricultural sorts, nor whether they are associated with other characters than the failure to produce intermediates. Heritable variations in the amount of fertility in the lateral florets of 6-rowed barleys have been noticed, however, and since the conception of a regressive 6-rowed type offers a possible explanation of their behavior, a statement concerning these unusual varieties may be of interest.

In 1909 the senior author noticed a decided tendency to sterility of lateral florets in the agronomic varieties known as Mansfield and Summit. In each case the earliest spikes to appear were normal 6-rowed spikes. The lateral florets were highly fertile, long awned, and produced large kernels. In the later spikes, especially where the plants produced several culms, the lateral florets exhibited increasing sterility. Late spikes, in which none of the lateral florets were fertile, were found in many plants. One of these barleys, Mansfield, was the progeny of a cross between a 6-rowed and a 2-rowed barley, made at Guelph, Ont., in 1891. The peculiar behavior of this variety was so striking that selections of fertile and infertile spikes were made in 1909. These were planted in 1910, but, as would be expected, there was no difference in their inheritance. Owing to seasonal conditions the percentage of spikes with no fertility in the lateral florets was unusually large in 1910, the sterile spikes being approximately equal to the fertile in number. Spikes from a single plant are shown in Plate 105, D. It will be seen that the sterile florets are

long awned and that there is no approach toward the homozygous intermediate. The second variety, Summit, which for other reasons is thought also to be of hybrid origin, produced spikes with infertile lateral florets much more rarely. It is suggested that these barleys may be forms of the 6-rowed segregate AAbbcc, homozygous for the absence of the two secondary factors of fertility.

POSITION OF FERTILE LATERAL SPIKELETS

Aside from the question of the amount of fertility in the lateral florets, the location of fertile florets on the spike is of interest. In the common varieties of barley the largest kernels are produced about one-third of the distance from the base of the spike to the tip, in both the central and the lateral spikelets. The longest awns are attached to these florets, and they exhibit a progressive decrease in length toward the tip of the spike. The fertility of the homozygous intermediate runs in the reverse order. When only a few kernels are produced they are found in the upper third and gradually extend downward from the tip in the more fertile intermediates. The most fertile lateral florets in the Mansfield variety are found near the center of the spike.

ABERRANT LINE NO. 37

In Table I line No. 37 was found to differ greatly from the other members of group 2 in both appearance and fertility. It is much lower in fertility than the other individuals and, with the exception of one or two florets, is similar in appearance to the fixed intermediate. This plant is the only one of the 87 whose appearance is difficult to explain. It is not believed that the hypothesis of its being homozygous for the absence of the third factor is adequate explanation for its wide departure from type. For this reason this line was excluded in the later discussion. It is possible that the supposed F_2 plant is the result of a natural hybrid. The appearance of the forms in any class varies with the parents used. Some combinations result in greater fertility in the various classes, others result in much less. If the F_1 kernel from which this F_2 plant developed had been fertilized by some neighboring 6-rowed variety less vigorous than the Manchuria or by a low-fertility *intermedium* form, such a plant as No. 37 might result. The opportunity for accidental crossing in the F_1 generation is unusually good. The lateral florets of the F_1 plants are much more likely to open at flowering time than are the normal barley florets, and they flower after the spike is exserted. The flowering glumes are less interlocked and open more readily and more widely. The flowers are more frequently deficient in pollen, and those not self-pollinated remain open for hours or even days, affording unusual opportunity for cross pollination.

SUMMARY

H. intermedium is a form of barley in which the awnless lateral florets exhibit a fertility greater than that found in the 2-rowed and less than that occurring in the 6-rowed barleys.

The occurrence of this form as a homozygote has been questioned frequently.

H. intermedium forms which are stable under all conditions of culture have been isolated from numerous crosses reported in this paper. This form appears to be genetically as distinct as either *H. vulgare* or *H. distichon.*

A 2-factor hypothesis for fertility in the lateral florets is suggested. On the presence-and-absence hypothesis the 6-rowed barleys are supposed to be homozygous for the presence of the epistatic factor, the *intermedium* to be homozygous for the presence of the hypostatic factor and for absence of the epistatic factor, and the Svanhals to be homozygous for the absence of both factors.

According to the hypothesis, there are two types of 6-rowed barleys. The Manchuria parent is supposed to be homozygous for the presence of both factors, while certain regressive 6-rowed segregates are thought to be homozygous for the presence of the epistatic factor and for the absence of the hypostatic factor.

There is evidence suggestive of a third factor which affects the vigor of the lateral florets and their percentage of fertility.

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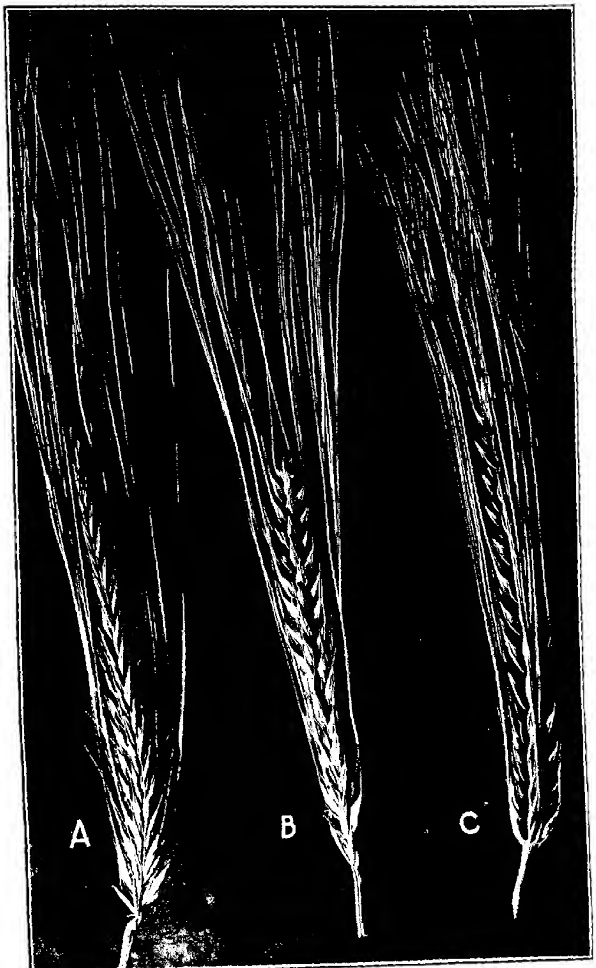
PLATE 103

Individual heads representing the three phenotypic progeny classes in which the lateral florets bear awns:

A.—Low-fertility class.

B.—High-fertility class.

C.—Manchuria parent representing the 6-rowed segregates.


A
B
C

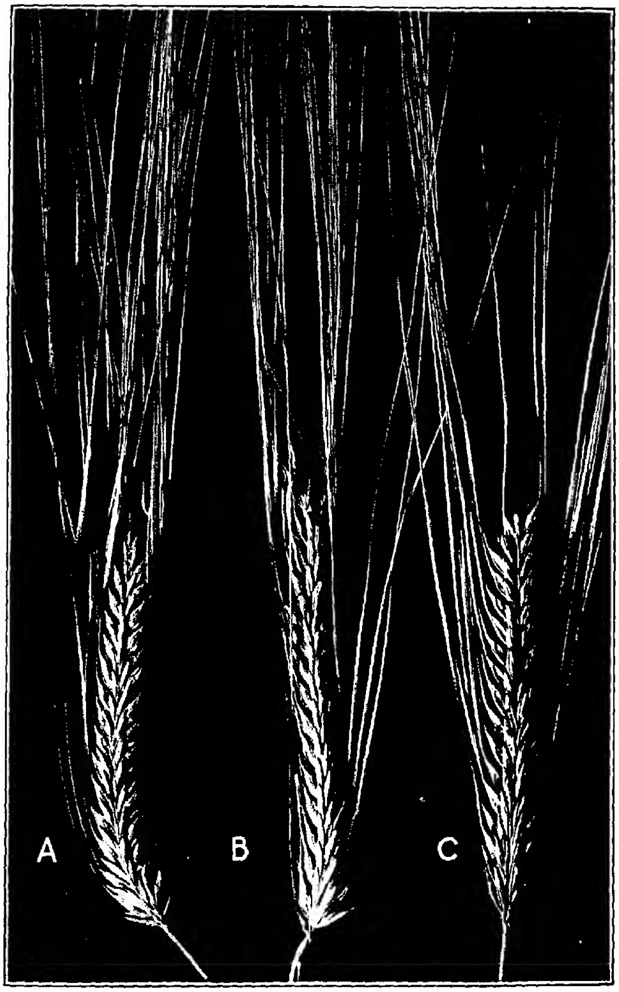

A
B
C

PLATE 104

Individual heads representing the phenotypic progeny classes in which the lemmas of the lateral florets are rounded and awnless:

A.—The 2-rowed, represented here by the Svanhals parent.

B.—Low-fertility class.

C.—*Hordeum intermedium.*

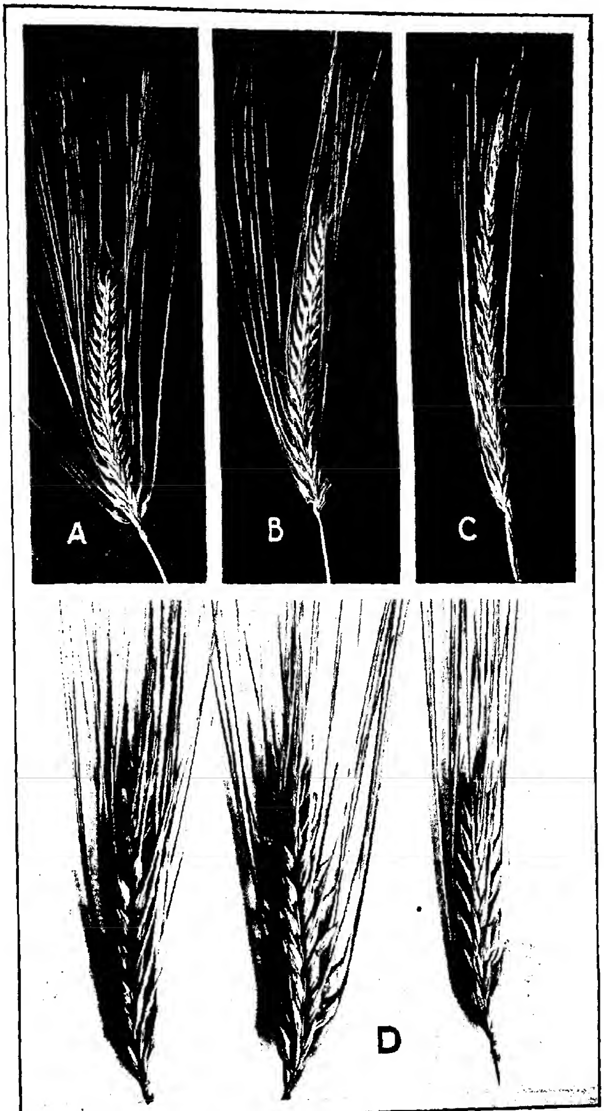
PLATE 105

A.—Awn-pointed individual, heterozygous for regressive 6-rowed and 2-rowed characters.

B.—Short-awned individual, heterozygous for regressive 6-rowed and 2-rowed characters.

C.—Long-awned individual, heterozygous for regressive 6-rowed and 2-rowed characters.

D.—Three spikes of Mansfield barley from the same plant, showing the variations of fertility in the lateral florets.


A
B
C
D

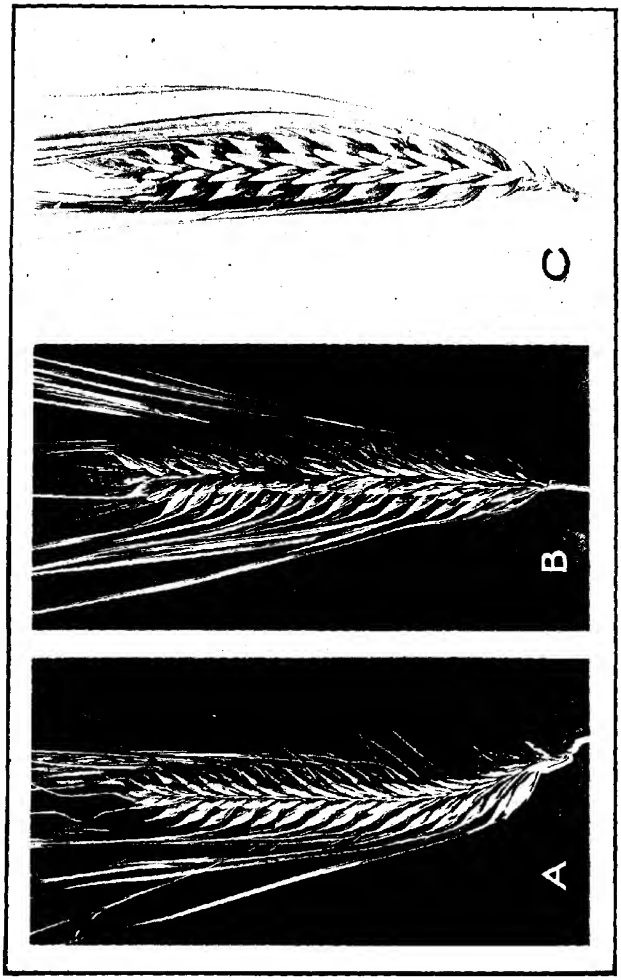

C
B
A

PLATE 106

A.—Infertile spike of potentially fertile *Hordeum intermedium*.
B.—Fertile spike of *H. intermedium*.
C.—Var. *atterbergii*, probably a sterile *intermedium*.

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